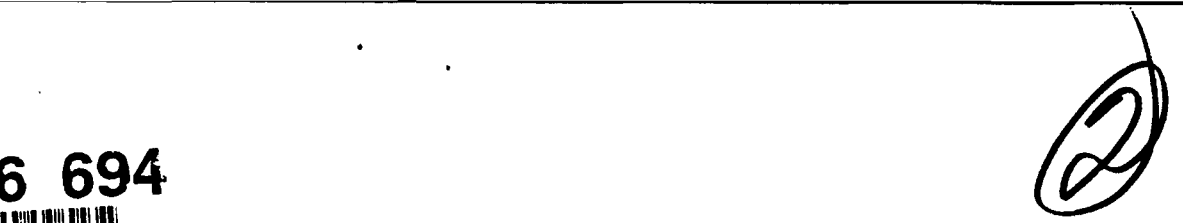

Validation and Verification Flight Test for TCAS-II Logic Changes (MOPS Change 6)

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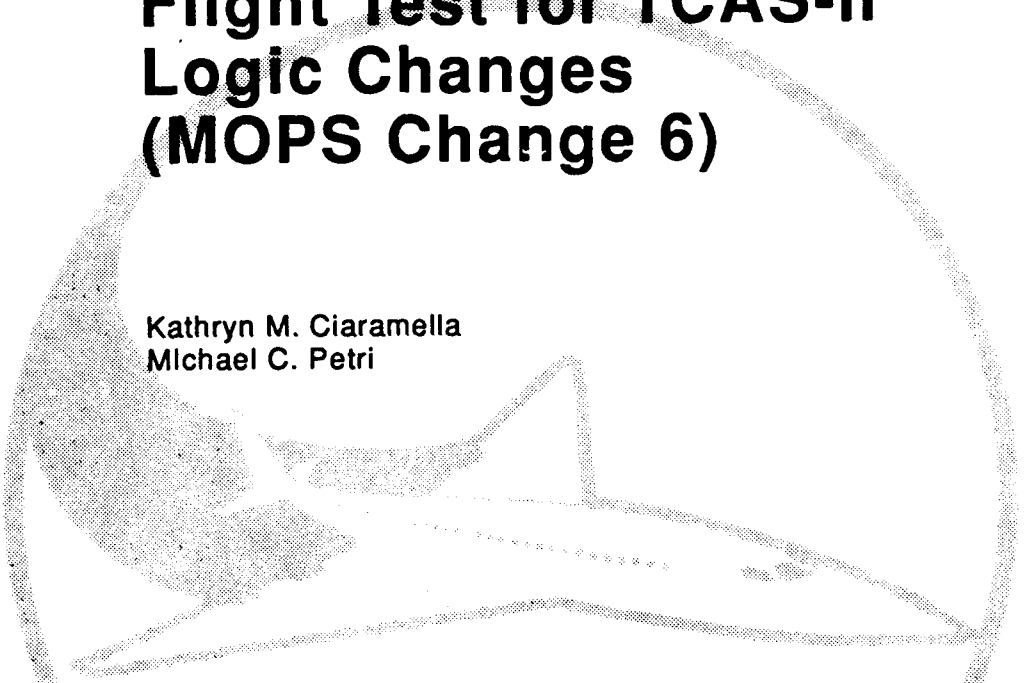
Michael C. Petri



December 1991

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U.S. Department of Transportation
Federal Aviation Administration

Technical Center
Atlantic City International Airport, N.J. 08405

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16. Abstract

A series of 24 two aircraft encounters were designed and executed to validate and verify the Change 6 Traffic Alert and Collision Avoidance System (TCAS)-II collision avoidance logic of February 1989. These tests were performed with several aircraft equipped with varying configurations of TCAS and Mode C. Technical Center pilots performed all of the logic test encounters. Technical Center and TCAS manufacturer company pilots performed the TCAS coordination test encounters. Industry pilots performed a pilot evaluation of the logic changes through execution of a subset of the encounters.

The logic flight tests demonstrated that the computer simulations of the encounters were accurate. The Change 6 logic successfully resolved all tested encounters, including those which would have resulted in "advisory invalid" enunciations in the Change 5 logic. The pilots generally accepted maneuvers suggested by TCAS as safe and appropriate for the flight geometries. The pilots did suggest improvements to the TCAS display logic, and many of these improvements were incorporated into the final Change 6 logic of September 1989.

The encounters have been updated to include all changes included in the final Change 6 logic in the event that additional flight tests are desired.

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EXECUTIVE SUMMARY

This document describes the results of the validation and verification flight tests performed on the Traffic Alert and Collision Avoidance System (TCAS)-II Change 6 logic. Previous versions of the TCAS logic could issue an "advisory invalid" on maneuvering aircraft. The Change 6 logic eliminated this problem by allowing advisory sense reversals and increase rate advisories. The flight tests were designed to validate and verify these and other changes to the logic, as well as evaluate pilot acceptance of these changes.

Computer simulations were used to design the 24 two aircraft flight geometries which stress the revised areas of the logic. A subset of these encounters was performed by a representative group of industry pilots to gather information on pilot acceptance of the new advisories.

The flight tests included TCAS to TCAS and TCAS to Mode C encounters, and were conducted using Technical Center test aircraft as well as Bendix and Honeywell corporate aircraft. Bendix and Honeywell TCAS-II Limited Installation Program (LIP) units programmed with the Change 6 logic of February 1989 were used for the tests. The flight tests were performed from April through June 1989.

The encounters were successful in generating the desired advisories. Analysis of the collected data showed that the TCAS logic performed well in all encounters. Some minor hardware and software implementation problems were found in the TCAS LIP units. Some minor problems with the logic design were also noted. None of these problems affected the testing or safety of the TCAS.

Computer simulation of the results, alternately using the Change 5 and Change 6 logic, shows that the Change 5 logic issues many "advisory invalid" enunciations for the test encounter set, while the Change 6 logic safely resolves all encounters.

Pilot acceptance of the new advisories was good. However, the pilots had several suggestions for improvements to the display logic, such as reducing the number of aural advisories. Many of these suggestions were included in the final version of the Change 6 logic (September 1989).

Appendix A includes the encounter descriptions used for the flight tests. Revisions to the logic after these flight tests were performed have altered the expected results of several of the test encounters. Those encounters affected by the changes have been updated to reflect the changes and are included in appendix B.

INTRODUCTION

PURPOSE AND SCOPE OF THIS DOCUMENT.

This document provides a description of the results of the flight test program, conducted from April through June 1989, for validating and verifying the Traffic Alert and Collision Avoidance System (TCAS)-II logic changes that are included in Change 6 to the TCAS-II Minimum Operational Performance Standards (MOPS). The document specifically addresses the performance of the revised coordination logic, the performance of the logic changes known as the "advisory invalid" alternative logic, and pilot acceptance of the logic changes.

BACKGROUND.

The TCAS-II logic has previously incorporated two features which have been of concern to pilots. These features are the "advisory invalid," and the altitude crossing resolution advisories (RAs).

The advisory invalid logic was necessitated by an earlier decision which mandated that TCAS could not issue advisories of conflicting sense during an encounter with another aircraft. As such, if the other plane maneuvered after an RA was chosen, or the TCAS pilot ignored the advisory, TCAS could predict that following the RA would no longer provide adequate separation. However, TCAS could not revise the sense of its issued advisory. The advisory invalid allowed the TCAS to notify the pilot that the current RA would not provide adequate separation.

The altitude crossing RAs usually occur when at least one of the aircraft involved in an encounter has a vertical rate. The greatest miss distance at closest point of approach (CPA) is sometimes obtained by crossing through the other aircraft's altitude. Pilots are not comfortable with these encounters since, at some point in the maneuver, both aircraft will be at the same altitude. This type of advisory can be thwarted by the level-off of either plane, which frequently causes an advisory invalid situation.

DESCRIPTION OF THE LOGIC CHANGES.

Change 6 of the TCAS-II logic addresses those features which were of concern to the pilots by eliminating the advisory invalid and biasing against altitude crossing maneuvers. This has been accomplished by adding several new features to the logic.

"ADVISORY INVALID" ALTERNATIVE LOGIC. The advisory invalid alternative logic was designed to provide advisories for those situations which previously would have caused "TCAS INVALID" enunciations. The alternative logic contains additional advisories, the sense REVERSAL advisory, and the INCREASE RATE advisories, to handle these situations.

Advisory Sense Reversal. A displayed reversal normally only occurs in a TCAS-non-TCAS conflict. This can occur in either a

crossing or noncrossing situation. In the crossing case, if the modeled response to a reversal during the execution of an advisory exceeds the maximum bound on the intruder's relative altitude at CPA, a reversal is issued. This reversal is issued to eliminate the occurrence of an altitude crossing. In an initial noncrossing situation, if the non-TCAS aircraft accelerates vertically or if the TCAS pilot fails to maneuver in response to the RA, and the intruder crosses through the TCAS aircraft current altitude, a reversal is issued. This reversal prevents the TCAS from crossing through the intruder's altitude a second time.

In a fully coordinated TCAS-TCAS encounter, no displayed RA may be reversed. However, a nondisplayed reversal may occur during the coordination process (see "Revised Coordination Logic" below).

It is possible for the high MODE S identification (ID) to reverse its displayed advisory sense in a TCAS-TCAS conflict, but only under specific conditions. If the high MODE S ID declares the other TCAS aircraft a threat, but cannot establish coordination within three system cycles, it will display its selected RA. If coordination is established during the next three cycles, however, and the low MODE S ID has selected an incompatible advisory, the high MODE S ID TCAS must reverse its displayed advisory sense. Both types of TCAS-TCAS reversal processes require timing and aircraft positions too critical to be flight tested.

Increase Rate Advisory. The increase vertical rate RA is used in situations in which a TCAS aircraft executing the nominal escape maneuver (+/-1500 feet per minute (fpm)) would not be able to achieve sufficient separation from a Mode C or TCAS intruder. Once this situation has been detected, an advisory to increase the vertical rate from 1500 to 2500 fpm in the existing sense is displayed. In order for an increase rate RA to be issued, the current RA must be positive (CLIMB or DESCEND), increase rate RAs must not be inhibited (inhibition occurs because the aircraft are about to diverge or the aircraft is performance limited), and a sense reversal must not have been issued on the current cycle.

An increase rate advisory may also be issued for an encounter which would, if more time to CPA was available, generate a sense reversal. In this case, if there is insufficient time to execute a reversal (10 seconds (s) or less) and the logic projects the intruder altitude at CPA will be within 200 feet (ft) of the current TCAS altitude, an increase RA is issued.

BIAS AGAINST ALTITUDE CROSSING ADVISORIES. Several features have been added to bias against altitude crossings, which were the primary source of invalid advisories. The first feature allows the logic to choose a noncrossing advisory which will provide adequate separation over an altitude crossing advisory providing superior separation.

Another feature allows a level TCAS in a crossing situation to defer to a maneuvering TCAS intruder for as long as 3s when selecting an initial RA. This delay allows the maneuvering TCAS to select the

advisory sense and initiate the coordination, thereby reducing the chance of an altitude crossing.

The third feature, the 900-ft rule, has been developed for situations involving intruder level offs 1000 ft above or below own aircraft. No RA will be issued if the intruder aircraft is projected to cross own aircraft's altitude, as long as the current altitude separation exceeds 900 ft (or the altitude threshold of the current sensitivity level if it is greater).

REVISED COORDINATION LOGIC. Change 6 of the TCAS-II logic also includes refinements to the TCAS-TCAS coordination logic. These refinements were made to eliminate the need for including special logic in the Mode S transponder, and because of the difficulty in designing MOPS tests to verify the coordination process.

The new coordination logic is based on the sense reversal concept used to eliminate the advisory invalid indication, but is independent of that logic. The idea of coordination is for compatible senses to be selected by both aircraft. Before each aircraft selects its sense it looks for an RA complement from the other aircraft. The first aircraft that recognizes the threat situation and chooses an RA sense does so by the geometry of the encounter. It will then communicate its RA complement to the second aircraft. The second aircraft receives the RA complement and selects the sense opposite the first aircraft's RA.

Situations which would previously have caused a "tiebreaker" condition have been eliminated in the revised logic. The TCAS with the higher Mode S ID now defers displaying its RA for up to 3s while waiting to receive an intent message from the other aircraft. The TCAS with the lower Mode S ID can display its RA to the pilot immediately. During the time the higher Mode S ID TCAS is waiting to receive an intent message from the other TCAS, it sends its own intent in case it is the first to recognize the threatening situation. In the event that incompatible senses are selected, the TCAS with the higher Mode S ID will reverse its sense before displaying the advisory to the pilot.

These changes have simplified the processing logic located in the Mode S transponder. A lock request message is no longer needed. Resolution intent messages are the only required messages for TCAS coordination.

CHANGE 6 REVISIONS SINCE EXECUTION OF THE FLIGHT TESTS. The logic used in this flight test was dated February 6, 1989. Several logic changes were made after this date but prior to approval of the Change 6 logic by the Radio Technical Commission for Aeronautics (RTCA) in September 1989. These changes were the result of analysis of the flight data collected in these tests, as well as additional analysis of the Limited Installation Program (LIP) data, additional discussion of display requirements by pilot groups, and additional logic tuning by The MITRE Corporation. These changes were validated and verified by MITRE. No additional flight tests were performed.

General Logic Revisions. The 900-ft rule has been revised to become the 600-ft rule. This change was made because the 900-ft altitude limit is often violated by planes leveling off at 1000-ft separations. Pilot interviews and analysis of flight data indicate that aircraft often overshoot the level-off altitude. The tracker lag in the TCAS tends to indicate that a target aircraft has continued its vertical rate when leveling off. This change should compensate for overshoot and tracker lag, thereby eliminating more advisories on planes leveling off at 1000-ft separations. The 600-ft rule also provides a further bias against altitude crossing RAs issued on visual flight rules (VFR) aircraft that level off at 500-ft separations.

The pseudocode was modified to handle the interaction of biases against altitude crossing RAs with CLIMB INHIBIT and DESCEND INHIBIT indications.

The altitude at which INCREASE DESCEND RAs are inhibited was lowered from 1800 to 1450 ft above ground level (AGL).

The altitude at which DESCEND RAs are inhibited has been raised from 700 to 1000 ft AGL. This change will prevent occurrences of ground proximity warnings and dropping below the glide slope due to low altitude DESCEND RAs.

The cases where INCREASE RAs downgrade to positive RAs, the displayed rate will be the larger of the nominal goal rate (1500 fpm) or own aircraft's current tracked rate.

Display Logic Revisions. INCREASE RAs will not be displayed if own aircraft's current vertical rate exceeds 2500 fpm.

The logic was modified to prevent a second REVERSAL enunciation when an INCREASE RA which follows a REVERSAL RA is downgraded.

The hysteresis applied to the RA goal rate to determine when the RA is corrective was increased from 150 to 300 fpm. This eliminates some of the problems caused by the tracker lag in which the indicated vertical rate was outside of the red arc, but a corrective RA was enunciated.

Separate CLIMB and DESCEND sense corrective flags were added for use with multiaircraft threats when composite RAs of different vertical sense are required.

The corrective RA is now maintained until the RA is weakened so that the "fly to" arc remains illuminated.

The CLIMB INHIBIT and INCREASE CLIMB INHIBIT flags are latched when own aircraft is at climb inhibited altitude and an RA is issued to prevent fluctuations in RA strength.

The order of precedence for control field flags in the ARINC 735 DITS word 270 has been established. This word contains the output data for the RA display, traffic display, and the aural enunciation subsystems.

Enunciation of a REVERSAL RA is inhibited during multiaircraft encounters in which a positive RA against more than one threat becomes MAINTAIN ALTITUDE RA because one or more of the threats has leveled off. A CLIMB REVERSAL RA will be maintained for at least 5s, even if own aircraft is climb inhibited, to prevent the change on the very next cycle to a DON'T DESCEND RA.

TEST OBJECTIVES.

The two major objectives of the flight test were to evaluate the technical performance of the logic changes under actual flight conditions and to determine pilot acceptance of the escape maneuvers introduced by the new logic (i.e., reversals and increase rate advisories). Both were accomplished.

DESCRIPTION OF THE EQUIPMENT.

The equipments used for this validation flight test were TCAS-II units flown in the United/Bendix and Northwest/Honeywell Limited Installation Programs. The Change 6 logic of February 1989 was installed in these LIP units and run through extensive factory and MOPS tests to verify the correct implementation of the TCAS pseudocode prior to shipment to the Technical Center for these tests.

The major system components and their relationships are shown in figures 1 and 2.

EQUIPMENT INSTALLATION.

INSTALLATION ON THE TECHNICAL CENTER AIRPLANE. Both the Honeywell and the Bendix LIP TCAS-II systems were installed in the Technical Center Boeing 727 airplane (N-40). Components located in the cockpit and required aircraft equipment are indicated in figures 1 and 2. The Instantaneous Vertical Speed Indicators (IVSIs) were installed in the instrument panel, replacing the standard IVSIs. The Bendix Traffic Advisory Display Unit and Control Panel and the Modified Color Weather Radar for the Honeywell were alternately installed in the center console. The bulk of the equipment was installed on racks in the front of the passenger compartment.

After installation, the TCAS equipment was tested for proper operation. Ground testing was accomplished by monitoring visible airport traffic and comparing it with the TCAS-II display data. Check flights were flown after each installation to verify basic system performance.

INSTALLATION ON MANUFACTURER'S AIRPLANES. The coordination flight tests required two TCAS equipped aircraft. Both of the TCAS manufacturers provided a second TCAS unit equipped airplane for these tests. The Bendix TCAS was installed in their Sabreliner corporate jet. The Honeywell TCAS was installed in their Kingair corporate jet. Both planes had been equipped with the TCAS units for corporate testing prior to their use at the Technical Center for the coordination testing. Each of these planes visited the Technical

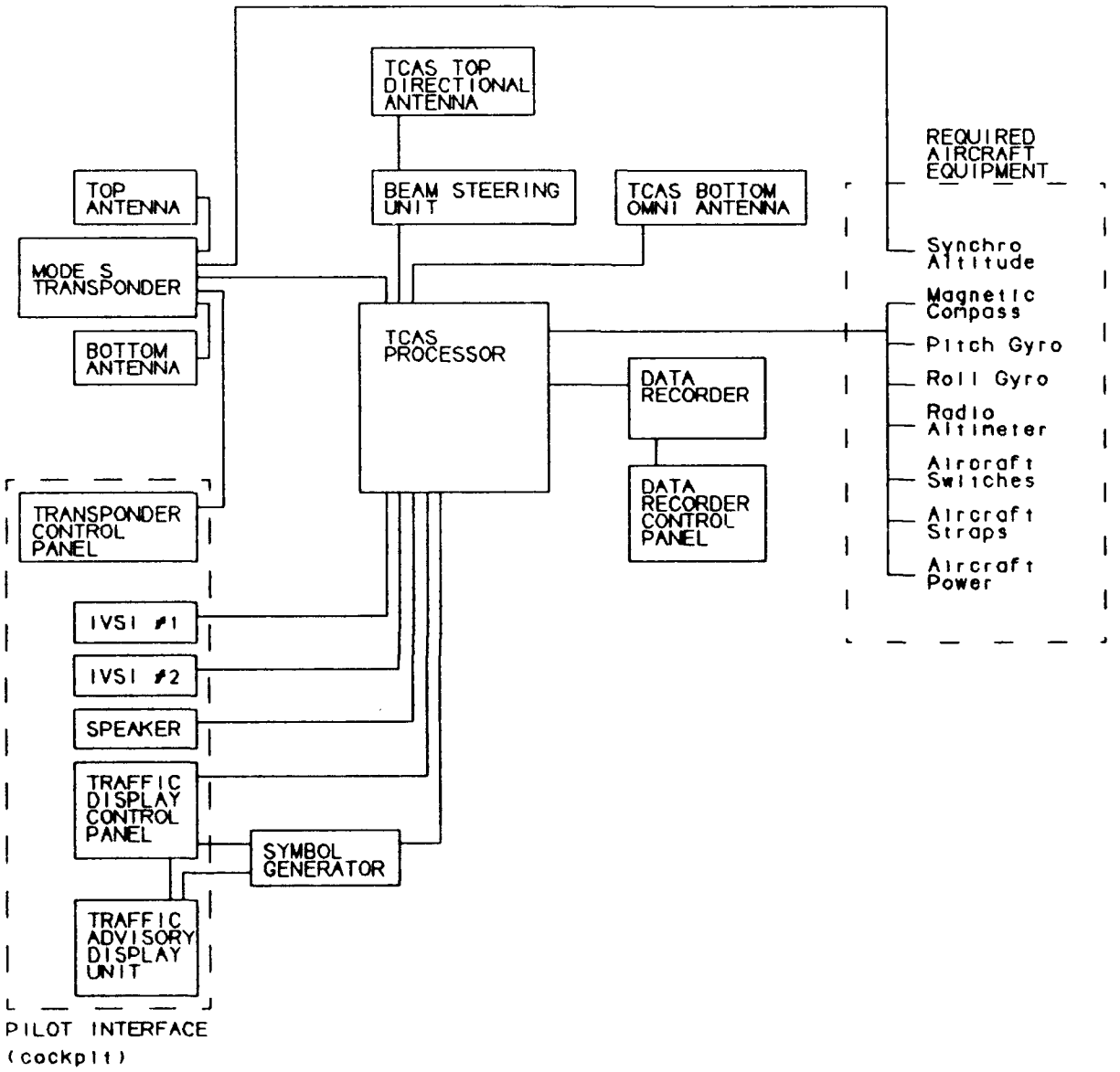


FIGURE 1. BENDIX LIP TCAS-II SYSTEM COMPONENTS

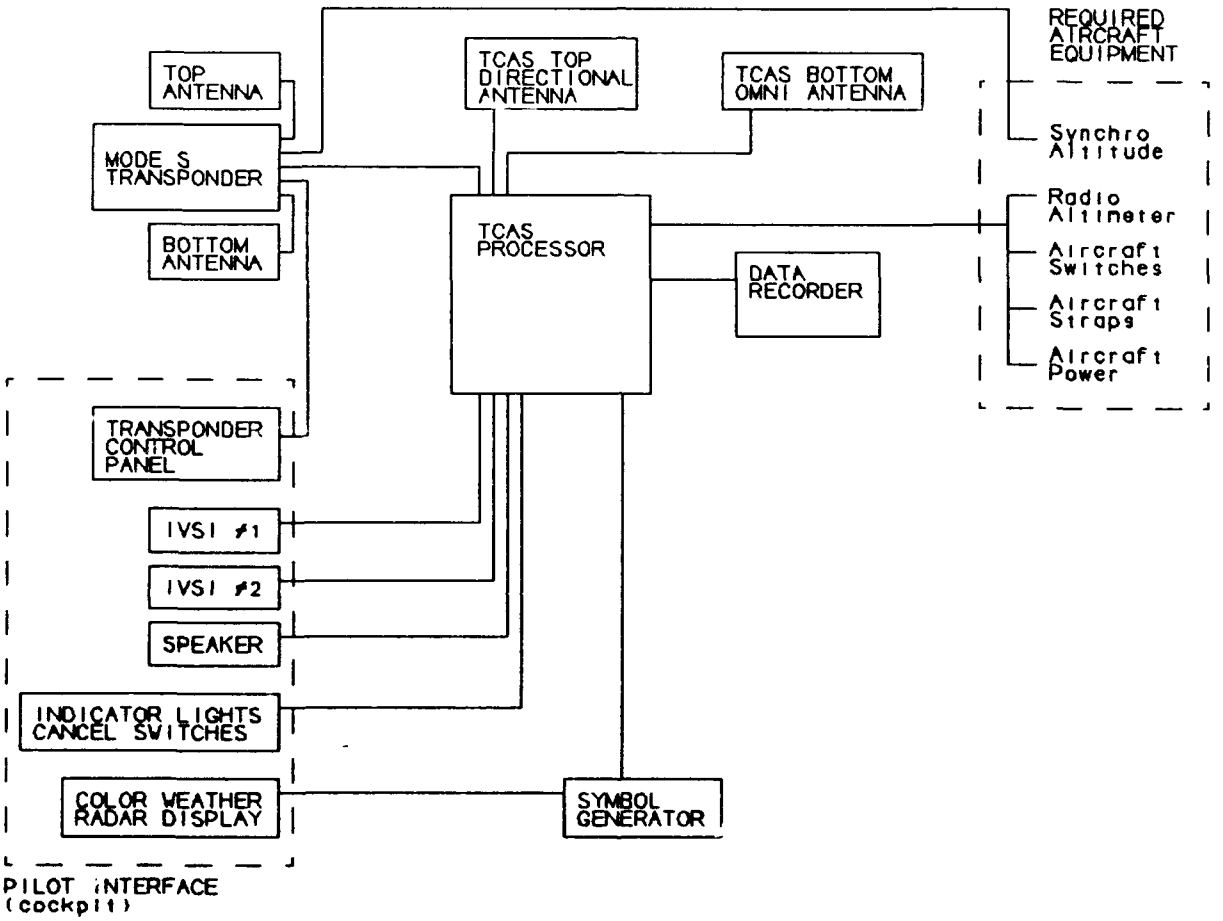


FIGURE 2. HONEYWELL LIP TCAS-II SYSTEM COMPONENTS

Center only for the time necessary to perform the TCAS to TCAS coordination flight tests.

TEST DESCRIPTION

TEST DESIGN.

GENERAL. The flight tests were outlined in the Validation Flight Test Plan for TCAS-II Logic Changes (MOPS Change 6), division report ACD-320-89-1. Because Change 6 of the logic focused on a small segment of the advisory choices (those situations which would formerly have caused altitude crossings or advisory invalids), the flight test also focused on flights which would exercise this specific logic. This was done by flying two airplanes together on near collision courses such that these specific areas of the TCAS logic would be used. Most of the flights, therefore, involve at least one maneuvering aircraft. The special cases for delaying RA choice or coordination (the 900-ft rule and the level wait) were also chosen for testing.

The basic encounter types were set up and then run through the Technical Center's flight simulation computer program to find the timing, airspeeds, maneuvering distances, vertical rates, etc., that would result in the desired paths through the logic. Thousands of simulations were run to determine these parameters. The test plan encounters were then chosen from these simulations for ease of execution. Several of the runs were further modified and simulated again to obtain more easily achievable results.

The outputs of these simulations were then used to create the encounter descriptions. All information critical to the encounters is contained in the descriptions.

Most of the encounters require at least one of the airplanes to maneuver precisely to trigger the appropriate section of the TCAS logic. As such, some method of measuring the time or distance between the two airplanes is necessary to perform the encounters. The encounters were designed to use the TCAS to trigger all maneuvers, thus, eliminating the need for any special equipment other than the TCAS, a timepiece, and a radio link to the target aircraft. All timing for maneuvers is based upon the occurrence of traffic alerts (TAs) and RAs.

Expected ranges at the time of some events are included in the encounter descriptions. These ranges were used during some of the encounters, along with the air to air Tactical Air Navigation System (TACAN), to adjust the encounters.

MODIFICATIONS TO ENCOUNTERS DURING THE FLIGHT TEST PERIOD. By following the encounter geometries as simulated, it was expected that TCAS results similar to those obtained in the simulations would be obtained. However, these flight geometries are difficult to set up and the need for some adjustments was expected. Technical Center personnel monitored each run and made slight adjustments as necessary to obtain the desired results. Specific advisories were the desired

result, so any variations on the written geometry that produced these RAs were considered acceptable.

Those encounters which had little success were examined, resimulated on the computer, and revised to more easily achievable encounters. As a result of the revisions, several encounters were altered from their original designs. The changes to the encounters are summarized in table A-1 in appendix A.

MODIFICATIONS TO THE ENCOUNTERS DUE TO CHANGE 6 UPDATES. As a result of updates to the Change 6 logic which were approved after these tests, several of the encounters require modification to continue to test the logic. These encounters have been updated using the same process as the original encounter design. While these encounter updates were not part of the flight test, they may be used for further testing and are included as the encounter descriptions in appendix B.

ENCOUNTERS AND RUNS. Each of the planned flight geometries is referred to in this report as an encounter, while the specific performance of any of these encounters is referred to as a run. Since the runs do indicate the intended encounter geometry, however, the encounter geometries are often referred to as runs. Confusion over these terms may be eliminated by considering them synonymous.

The runs are identified by the encounter number in the data, with the addition of an identifier for repetitions of the same encounter (that is, the first of two performances of encounter 1 would be numbered run 1, and the second as run 1A). In the pilot evaluation phase of the flight, the run numbers also include a numerical prefix to indicate a specific pilot (i.e., run 1-3B refers to the third execution of Encounter 3 by pilot number 1).

ENCOUNTER DESCRIPTION.

The test plan specifies 24 encounters. The encounters have been organized with the TCAS to Mode C encounters (encounters 1-17) grouped before the TCAS to TCAS encounters (18-24). Many of the encounters within these two groups involve identical set-up geometries, such as encounters 20-23, but vary because of different pilot response to the TCAS advisories. These encounters start with both pilots ignoring advisories, followed by one TCAS pilot responding to the advisories, and concluding with both TCAS pilots following the advisories.

Table 1 lists each run, the logic tested, and the expected advisories. All of the TCAS-TCAS encounters will be used to evaluate the revised coordination logic.

There are four basic encounter types included in this test plan. They are listed below, with a brief description of the geometry (assuming no pilot response to the TCAS advisories), the encounter numbers of each type, and a brief description of the tested logic. The complete encounter descriptions are contained in appendix A.

TABLE 1. SUMMARY OF LOGIC TESTED AND EXPECTED ADVISORIES FOR EACH ENCOUNTER

Encounter	Logic Test	Expected Advisories
1	Basic Test	DESCEND
2	Basic Test	DESCEND, DON'T CLIMB, LIMIT CLIMB 1000 fpm
3	RA REVERSAL	CLIMB, DESCEND, DON'T CLIMB
4	RA REVERSAL	CLIMB, DESCEND, DON'T CLIMB
5	RA REVERSAL	CLIMB, DESCEND
6	RA REVERSAL	DESCEND, CLIMB, DON'T DESCEND
7	INCREASE RA	CLIMB, INCREASE CLIMB, CLIMB
8	INCREASE RA	DESCEND, INCREASE DESCEND, DESCEND
9	INCREASE RA / RA REVERSAL	DON'T CLIMB, DESCEND, INCREASE DESCEND, DESCEND
10	INCREASE RA	DON'T CLIMB, DESCEND, INCREASE DESCEND, DESCEND
11	RA REVERSAL / SLOW OVERTAKE	DESCEND, CLIMB, LIMIT DESCEND 1000 fpm, LIMIT DESCEND 2000 fpm
12	INCREASE RA / SLOW OVERTAKE	DESCEND, INCREASE DESCEND
13	900 ft RULE	DESCEND, LIMIT CLIMB 1000 fpm, LIMIT CLIMB 2000 fpm
14	INSUFFICIENT TIME FOR RA REVERSAL / INCREASE RA	CLIMB, INCREASE CLIMB
15	DESCEND INHIBIT	DESCEND, DON'T CLIMB
16	INCREASE DESCEND INHIBIT	DESCEND, INCREASE DESCEND
17	INCREASE DESCEND INHIBIT	DESCEND
18	COORDINATION	(plane 1) DESCEND (plane 2) CLIMB

TABLE 1. SUMMARY OF LOGIC TESTED AND EXPECTED ADVISORIES FOR EACH ENCOUNTER (CON'T)

Encounter	Logic Test	Expected Advisories	
19	COORDINATION	(plane 1)	DESCEND, LIMIT CLIMB 2000 fpm
		(plane 2)	CLIMB, LIMIT DESCEND 2000 fpm
20	INCREASE RA / COORDINATION	(plane 1)	CLIMB, INCREASE CLIMB
		(plane 2)	DESCEND, INCREASE DESCEND
21	INCREASE RA / COORDINATION	(plane 1)	CLIMB, INCREASE CLIMB, CLIMB, LIMIT DESCEND 500 fpm
		(plane 2)	DESCEND, DON'T CLIMB
22	INCREASE RA / COORDINATION	(plane 1)	CLIMB, INCREASE CLIMB, CLIMB
		(plane 2)	DESCEND
23	INCREASE RA / COORDINATION	(plane 1)	CLIMB, INCREASE CLIMB, LIMIT DESCEND 2000 fpm
		(plane 2)	DESCEND, LIMIT CLIMB 2000 fpm
24	COORDINATION	(plane 1)	DESCEND, LIMIT CLIMB 1000 fpm, LIMIT CLIMB 2000 fpm
		(plane 2)	CLIMB, LIMIT DESCEND 2000 fpm

Head-ons. In these encounters, the two airplanes fly toward each other on parallel courses. The courses are horizontally and vertically displaced from each other (figure 3).

Encounters 1, 2, 18, and 19 are general logic and coordination test runs. They will provide a quick indication that the TCAS unit or units are functioning properly.

Encounter 15 is a low altitude head-on designed to check the DESCEND INHIBIT below 700 ft logic.

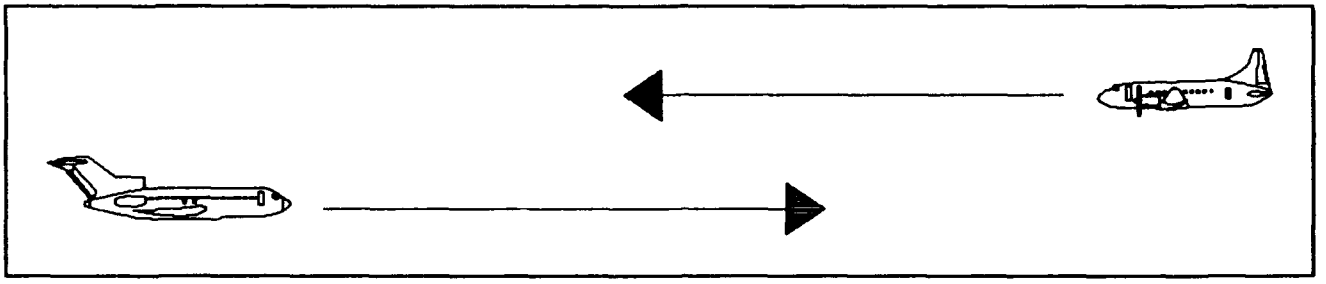


FIGURE 3. BASIC HEAD-ON GEOMETRY

Altitude Crossings. In these encounters, the two planes are flying toward each other on a horizontally parallel course. One plane is maneuvering vertically towards the other (i.e., descending toward a plane at a lower altitude), and at some point they will cross altitudes (figure 4).

Encounters 7, 8, 9, and 10 test the INCREASE RA logic. Encounters 20, 21, 22, and 23 test the INCREASE RA and RA REVERSAL logic.

Encounter 14 tests the INSUFFICIENT TIME TO EXECUTE A REVERSAL and INCREASE RA logic.

Encounters 16 and 17 test the INCREASE DESCEND INHIBIT at low altitudes logic.

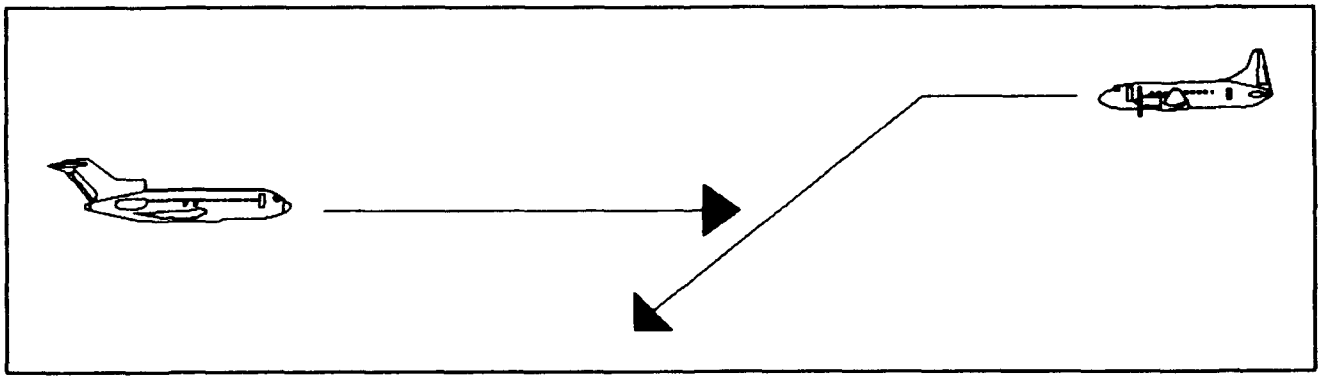


FIGURE 4. BASIC ALTITUDE CROSSING GEOMETRY

Vertical Fake-outs. These encounters are similar to altitude crossings, except the vertically maneuvering aircraft levels off before crossing the other plane's altitude (figure 5).

Encounters 3, 4, 5, and 6 test the RA REVERSAL due to intruder level-off logic. Encounter 24 tests the LEVEL-WAIT logic. Encounter 13 tests the 900-ft rule.

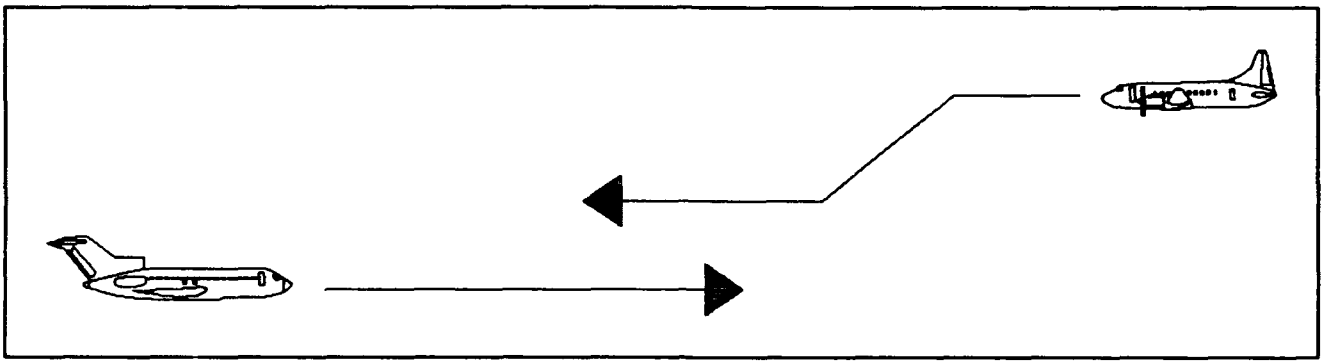


FIGURE 5. BASIC VERTICAL FAKE-OUT GEOMETRY

Tail Chase. In these encounters, the planes are flying in the same direction on parallel courses. One plane is flying faster, however, and will overtake the other. In these tests, the tail chases also include a vertical maneuver. As the faster plane, which is at the higher altitude, closes in on the slower plane, it begins a descend maneuver (figure 6).

Encounter 11 tests the SLOW OVERTAKE and RA REVERSAL logic. Encounter 12 tests the SLOW OVERTAKE and INCREASE RA logic.

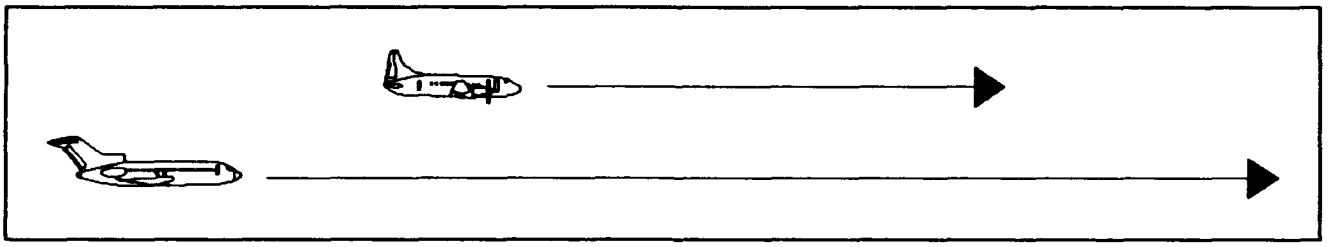


FIGURE 6. BASIC TAIL CHASE GEOMETRY

INDUSTRY PARTICIPATION.

TEST PLAN. The test plan, including all encounter descriptions, was prepared at the Technical Center with assistance from George Lyddane, ANM-104N, and TCAS personnel from The MITRE Corporation and the Massachusetts Institute of Technology Lincoln Laboratory. The test plan was presented at the RTCA SC-147 (Special Committee 147 - Minimum Operational Performance Standards for Traffic Alert and Collision

Avoidance Systems Airborne Equipment) for review. Finally, comments on the plan were solicited prior to final publication.

PILOT SELECTION AND PARTICIPATION. The second objective of the flight plan was to determine pilot acceptance of the escape maneuvers introduced by the new logic. This required the participation of a range of commercial pilots. Pilots were chosen through the Air Line Pilots Association (ALPA) and the Separation Assurance Task Force (SATF) to participate in this phase of the flight tests.

The pilot evaluation flight tests consisted of a subset of the specified encounters which were chosen to familiarize the pilot with TCAS performance, and then present him with the new advisories (Encounters 2, 4, 6, 7, 8, and 12). Six flights were conducted, with approximately four pilots on each flight.

The test plan called for two of the pilots on each flight to individually fly the subset of encounters, while the other pilots served as observers. The actual number of participants varied slightly from flight to flight, depending on the weather and pilot availability. All pilots participated in the pre and post-flight briefings. Table D-6 (appendix D) lists the pilots who actually flew the encounters and their affiliations.

TEST CONDUCT.

GENERAL. After installation of each TCAS aboard N-40, a system checkout flight was performed to ensure the proper operation of the system. Due to limited availability of the second TCAS equipped aircraft, the runs were split into two sets, the TCAS/Mode C and TCAS/TCAS runs. The TCAS/TCAS runs were performed using the manufacturers aircraft as the target aircraft.

In the TCAS/TCAS encounters, the encounter geometries were easily executed by using the TCAS installed on either plane for timing information.

In encounters with the Mode C plane, a TCAS participant sent radio messages to the crew in the Mode C plane based on the TCAS advisory timing. Generally, another TCAS participant would receive the messages and count out the needed delays before instructing the pilot to execute the maneuvers. Encounters which required this "remote control" were 3 through 14, 16, and 17. Several other encounters required the Mode C pilot to make a second maneuver based on altitude. These encounters are 3 through 6, 13, 16, and 17.

Even though most of the runs are based on the TCAS timing, each encounter includes some slant ranges near which the pilots may expect to receive the advisories or begin maneuvering. These distances were provided only to aid the pilots in preparing for the maneuvers, and were not to be the actual impetus for the maneuvers during the flight tests. However, some of the encounters were easier to set up and adjust by using these ranges along with the air to air TACAN installed on the FAA aircraft. This was especially true for all runs using the

Bendix TCAS-II, which did not include the modified tau criterion for TAs in the Change 6 logic. The Bendix system issued TAs at much greater ranges than would be expected with the proper logic.

(Note: Bendix had included the modified tau criterion for RAs. Only the timing of the TAs was affected by this omission.)

FLIGHT BRIEFINGS. Prior to each flight, the TCAS personnel and the pilots met to discuss the scheduled encounters and the expected results in detail. These briefings included pilot training for following the advisories. All questions about the encounters were answered at this time. The communications set-up between the two planes was made especially clear, including the system for synchronizing maneuvers from a single TCAS unit (see appendix A).

ENCOUNTER RULES. All encounters followed these rules:

1. Encounters will be made with nominal lateral offsets of 1/8 nautical mile (nmi) (769 ft) to 1/4 nmi (1519 ft) with both captains on the inside of each encounter for best visibility. This offset is included as a safety feature.

2. The captains will be responsible for the lateral separation on each encounter.

3. The flight crews must maintain radio communications with each other, as well as monitor the IVSI and altimeter for precision maneuvering.

4. All breakoffs will be to the right, with the higher plane climbing and the lower plane descending.

5. In-flight visibility of 7 nmi is required.

6. Visual contact is required prior to following RA. Landing lights may be used to aid visibility.

7. Loss of visual contact will require breakoffs.

8. All airspeeds listed in the encounter descriptions are true airspeed. These airspeeds should be maintained as best as possible through the vertical maneuvers by adjusting the aircraft thrust.

DATA COLLECTION.

FLIGHT LOGS AND DATA RECORDINGS. On all flights, TCAS personnel were located in positions to monitor and record on flight logs the performance of the TCAS equipment, as well as the progression of the encounters and pilot response to the encounters. The flight logs include information that assists in the flight data analysis, such as the start and stop time of each run, the run and encounter number, the time and range of target acquisition and TCAS alarms, and the times and ranges of any target anomalies, such as drops or splits. The flight logs also include time information on the data recording

periods, as well as any system anomalies (such as hang-ups or error conditions).

The TCAS data recorders were used for all flights. In addition, some video tapes of the traffic display and IVSI lights were made, as well as audio tapes of the aural advisories. The audio and video recordings were useful for reexamining any peculiarities in the displays, advisories, or TCAS performance noted during the flights.

The test plan specified that high resolution own aircraft data recording was to have been used to analyze pilot responses to the TCAS, such as delay times and vertical accelerations. However, the recording system was not available during the test period.

PILOT QUESTIONS. During the pilot evaluation phase of the test plan, the subject pilots were asked the following questions after each encounter:

How was your workload affected?

Were the alarms issued in a timely manner?

Were the alarms clear and unambiguous?

Did following any of the commands seem to make the situation more dangerous?

Were any advisories inappropriate?

Would you have preferred any different advisories?

Were you concerned with the course (altitude) deviation?

Did the TCAS display data help you sight the target?

Did you see the target plane before the RA?

Were you able to see the target plane throughout the maneuvers?

What is you opinion of the TCAS performance?

The answers to these questions, along with the TCAS aural advisories, were recorded on the audio tape recorder.

POST-FLIGHT DEBRIEFINGS. A post-flight debriefing was held after each flight to discuss each pilot's response to the above questions, and to discuss the overall impressions of the TCAS equipment performance, and the Change 6 logic in particular. Any anomalies noted during the flight were also discussed.

TEST RESULTS

COLLECTED DATA.

A total of 22 Change 6 test flights were performed. Appendix D contains flight data summaries. Table D-1 (appendix D) summarizes the dates, systems used, and runs flown for each flight. Tables D-2 and D-3 summarize the collected data by run number.

ANALYSIS OF TCAS RECORDED DATA.

SUCCESS OF THE ENCOUNTERS. The encounter geometries were designed to be as achievable as possible while testing the appropriate logic area to generate the desired advisories.

Geometries. No encounters requiring such precise aircraft positioning and maneuvering were ever attempted prior to the execution of the Change 6 flight test plan. The encounters require two aircraft, each travelling at an average true airspeed of 230 knots (kts) over a test range about 50 nmi long, to come together and maneuver at exact rates and accelerations at exactly the correct time. The correct time varies slightly depending on the positions of the airplanes and the measurement errors in the TCAS unit. As such, there was some doubt that the desired encounter geometries could be achieved. This doubt was erased during the first flight, when all but 2 of the 17 encounters flown were successful on the first attempt. Unfortunately, this high success rate was atypical.

Flight data from the first few flights was used to modify the encounters for a greater success rate. In runs 4, 9, and 10, the vertical rate of the target aircraft was increased from 1750 to 2000 fpm. This change allowed the vertical tracker to recognize the maneuver sooner, which increased the likelihood of obtaining a reversal.

The initial separations in runs 5 and 6 were increased by 300 ft to allow greater separation of the planes at the time of the planned reversal. It was found that even a small overshoot by either plane in the unmodified encounter would violate the 100 ft of vertical separation needed to issues an RA reversal. These revised encounters were flown using both the Bendix and Honeywell systems. There was some further difficulty with these encounters during the pilot evaluation flights of June 6 and 8 in which the target aircraft pilots were misinformed of their expected performance. In these cases, the target plane leveled off 200 ft closer to N-40 than expected. Once this misinformation was corrected, the new encounter design was easily flown.

The encounter geometry for run 14 was altered several times to increase the probability of success. The descent maneuver for the target was decreased from 2500 to 2000 fpm and was started 1s earlier. The slacken rate was changed to a level-off and occured 11s later. Even so, run 14 was only successful in 1 of the 20 times it was attempted. The precise timing of the intruder's maneuvers made it

necessary to use the air to air TACAN equipment to cue the intruder's maneuvers. The air to air TACAN was not functioning during the eight attempts at run 14 during the Honeywell equipment testing period.

Run 12, the slow overtake encounter, only produced the expected increase rate RA once, and this occurred on the first attempt of the encounter. The inability to reproduce this success was traced to a difference between the flight simulation computer program model of the parallel/overtaking aircraft paths and the actual flightpaths. This was due to the inability to describe and fly the encounter with the precision specified in the simulation. The simulated flightpaths are projected to come within 200 ft of each other, thus triggering the issuance of the increase rate RA. However, the actual flightpaths in the encounters were not projected to be within 200 ft. Therefore, no increase rate RA was needed.

The remaining 17 encounters were flown with repeated success as originally designed. The results were successful even with the small differences in the actual flight geometry of each run.

Advisories. Many of the encounters were designed for the sole purpose of exercising the advisory invalid alternative advisory logic included in Change 6. However, the required geometric accuracy required for entering this area of the logic (as discussed above) was difficult to achieve. It was even more difficult to enter the exact logic path suggested by a specific encounter description. Small variations in aircraft position, pilot performance, and TCAS measurements easily altered any of these encounters enough to result in a different advisory than expected (see the RA List field in table D-5, appendix D). These encounters still involved maneuvering aircraft, and the advisory invalid alternative logic was often exercised anyway. As such, the encounters often resulted in different Change 6 advisories than planned.

The point of the flights was to test these areas of the logic, not the pilots ability to set up the encounters accurately. As such, any encounter which resulted in the issuance of an increase rate or reversal RA was considered successful, even if the advisories were not expected for that encounter. All of the flight data were analyzed to insure that these advisories differed only because of the encounter geometry, not errors in the logic.

The encounters were very successful, overall, in generating invalid alternative advisories. Table D-4 (appendix D) summarizes the success of the encounters in generating the expected advisories (that is, those advisories described in the encounter description) and the success of the encounters in generating any invalid advisory alternative.

During the pilot evaluation phase of the flights, runs which generated one of the desired advisories were used no matter which encounter was being flown at the time. For example, if Encounter 4 resulted in an Increase Descend RA (expected from Encounter 8) instead of a Climb to Descend Reversal (as simulated), the run was counted as the Increase

Descend RA run instead of flying Encounter 8 to get the same advisory again. Encounter 4 would then be repeated to generate the Descend Reversal.

SEPARATION AT CPA. The altitude separation at CPA varied considerably from run to run of any encounter. This is easily explained by the slight differences in the actual encounter geometries and the differences in pilot performance. The separation was considered adequate by the pilots in all runs with the exception of one occurrence of run 17, which was not set up properly. (A detailed analysis of the TCAS performance during this run can be found in appendix C.)

The expected and actual altitude separations at CPA for those encounters in which the TCAS advisories were followed are listed in table D-5 (appendix D).

COURSE DEVIATION. The altitude deviations caused by following the change 6 commands have been of some concern. The expected and actual maximum and CPA altitude deviations are listed in table D-5. The maximum deviation often occurs after CPA, as corrective TCAS advisories are often still posted at or near CPA. The larger altitude deviations occur when the target airplane maneuvers to thwart the initial TCAS advisory.

TCAS PERFORMANCE PROBLEMS.

Several problems associated with the TCAS units were discovered during execution of the flight tests.

HARDWARE. Numerous problems were encountered with the flight data recorders on both TCAS systems. These problems resulted in the complete loss of data for 13 encounters using the Bendix system and 19 encounters using the Honeywell system.

Data analysis of Honeywell TCAS to TCAS flights revealed some peculiarities in the coordination process. These peculiarities were traced to the installation of a Change 5 logic transponder aboard the Honeywell Kingair, which resulted in a one-way coordination. The Change 5 transponder never accepted any received coordination messages. As such, those encounters in which the Change 5 transponder had the low Mode S ID, and, therefore, control of the encounter, were coordinated. Those encounters in which the Change 5 transponder had the high Mode S ID were uncoordinated. Sixteen of the recorded Boeing 727 encounters and 17 of the recorded Kingair encounters were affected by this error. All affected encounters were repeated after a proper transponder was installed.

Several deficiencies of the modified LIP systems that had been observed during the bench tests were also observed in flight. These deficiencies were deemed acceptable for these limited flight tests and were corrected in the production TCAS systems. The Bendix TCAS transponder occasionally provided a reply to a TCAS coordination interrogation without delivering the message to its TCAS unit. The

Honeywell TCAS would not always reinterrogate the required minimum six times when it was attempting Mode S surveillance at the same time as coordination.

SOFTWARE. Only one software problem was detected during the execution of the test plan. The Bendix system did not incorporate the Bramson criterion into its calculation of TAs. This omission caused the TAs to be issued at distances further than expected, which threw off the TA time based execution of the encounter geometries. The air-to-air TACAN was successfully used to complete these encounters in lieu of the proper TA timing.

COMPARISON OF PERFORMANCE WITH CHANGE 5 LOGIC.

Change 6 of the TCAS-II logic was primarily written to avoid altitude crossing advisories and eliminate the "advisory invalid." The benefits of these changes should be kept in mind when reviewing the test encounters, especially when reviewing some of the narrower altitude separations at CPA and large maximum altitude deviations.

The Technical Center flight simulation computer program was used to simulate the test encounters, using both the Change 5 and Change 6 logic. A comparison of the advisories generated by the two logic versions reveals the improvement in TCAS performance with the newer logic. These changes are summarized in table 2.

In the basic head-on encounters (runs 1, 2, 15, 18, and 19) there were no differences in the issued advisories. However, most of the altitude crossing encounters generated Advisory Invalid RAs in Change 5. These were replaced by Increase Rate advisories in Change 6. Most of the vertical fake-outs generated Advisory Invalid RAs in Change 5. These were replaced with RA Reversals in Change 6. All of the Advisory Invalid RAs issued by Change 5 have been replaced by advisories which produce adequate separation in Change 6.

PILOT EVALUATION OF CHANGE 6 PERFORMANCE.

PILOT DIVERSITY. Thirteen pilots flew encounters in the pilot evaluation phase of the tests. Eleven were airline pilots representing American, Continental, Delta, Northwest, Pan Am and United Airlines. One pilot was an aviation psychologist from the United States Air Force Instrument Flight Center. The other pilot represented the National Business Aircraft Association (NBAA). These pilots each flew encounters selected from the total test plan (runs 2, 4, 6, 7, 8, and 12) for a total of 99 encounters. Table D-6 (appendix D) shows the pilots, their affiliation, and the encounters flown by each pilot.

EVALUATION OF THE PILOT INTERFACES. The TCAS to pilot interface is the most visible aspect of TCAS, and generated the most negative comments and suggestions for improvement.

Aural Advisories Generated by TCAS. The aural advisories generated by TCAS were recorded with a hand-held cassette recorder

TABLE 2. COMPARISON OF FLIGHT SIMULATION RESULTS FOR CHANGE 5 VS. CHANGE 6

Encounter Number	Change 5	Change 6
Head-ons		
1,2,15,18,19		No change
Altitude Crossings		
7		No change
Note: A slight change in the encounter geometry would result in an ADVISORY INVALID for the Change 5 logic.		
8		INCREASE
9	ADVISORY INVALID	INCREASE/REVERSE
10	ADVISORY INVALID	INCREASE
14	ALTITUDE CROSSING	INCREASE
16	ADVISORY INVALID	INCREASE
17	ADVISORY INVALID	RA issued sooner
20	ADVISORY INVALID	INCREASE
21 and 23	*The initial maneuver of PLANE 2 is thwarted by a DON'T CLIMB advisory in Change 5, thus revising the encounter geometry.*	
22	ADVISORY INVALID	INCREASE
Vertical Fake-outs		
3	ADVISORY INVALID	REVERSE
4	ADVISORY INVALID	REVERSE
5	ALTITUDE CROSSING	REVERSE
6	ALTITUDE CROSSING	REVERSE
13	ADVISORY INVALID	900 FT RULE
24	ADVISORY INVALID	
Note: This is a marginal encounter for the ADVISORY INVALID. The Bramson criterion and the level-wait logic prevent Change 6 from issuing an INCREASE advisory.		
Tail Chase		
11	ALTITUDE CROSSING	INCREASE/REVERSE
12		INCREASE

Note: The Bramson criterion of modifying the alarm boundary affects the RA time in some of the encounters. This is most apparent in the tail chase, where the RA is issued 22 seconds earlier with Change 6.

from a speaker in the cockpit of N-40. These tapes were then transcribed, and the transcriptions are included in table D-7 (appendix D). These transcripts reveal some peculiarities with the specific TCAS unit in test, such as single repetitions of advisories and the lack of "clear of conflict" enunciations. There is an excessive amount of aural advisories during some runs. Finally, it should be noted that the actual TCAS advisory cannot be determined by many of the aural alerts.

Responses to Pilot Questions. The responses to the pilot questions asked after each encounter were transcribed. The transcriptions have been paraphrased for clarity and are included in table D-8 (appendix D). Specific negative pilot comments about TCAS performance are addressed in appendix C, Runs of Interest.

Results of Pilot Debriefings. Several of the questions asked of the pilots after each encounter generated answers which dealt specifically with the pilot interfaces. These issues were discussed in the debriefings and a consensus on the TCAS performance was usually reached. While the overall impression of the TCAS performance was always good, there were several negative comments about the pilot interfaces. Those specific runs which generated concern are denoted in the transcription, and a more detailed analysis of each concern is included in appendix C.

The output of the pilot briefings was collected by Ross Beins and summarized into a list of 10 "items which need to be addressed." The list, along with the reasons for, or the solution to each problem, follows.

1. Correct dropped tracks to insure the Clear of Conflict enunciation is issued.

Both tracking and surveillance have been improved to prevent tracks from dropping.

2. Prevent issuance of "Traffic Traffic" enunciation after target starts to diverge.

These enunciations were a result of track fragmenting. The TCAS units dropped the target near CPA, and formed a new track on it after CPA. The Traffic Traffic enunciation was issued on the new track. The correction in item 1 should eliminate this problem.

3. Check appropriateness of "Maintain Vertical Speed" after any other advisory.

The logic used to determine whether an advisory is corrective or preventive has been modified since the test flights. During the test flights, once the desired vertical rate was reached, the "Maintain Vertical Speed" was issued. The current logic now keeps the corrective advisory posted until the advisory is changed. The Maintain Vertical Speed is now issued if the current positive

advisory (Climb or Descend) is not corrective (i.e., if the pilot was already climbing or descending when the advisory was issued).

4. Determine why "Reduce Vertical Speed" can follow "Vertical Speed Restricted."

This is correct, and occurs when the vertical rate exceeds the IVSI limit shown.

5. Determine how "Descend" can follow a reversal ("Descend Descend Now").

The reversal flag in the logic only remained set for one cycle, during which the display logic would issue the "Descend Descend Now" command. During the next cycle, the display logic reevaluated the situation and, since the reversal flag was no longer set, decided a different aural advisory (i.e., "Descend") should be issued. The final version of the Change 6 logic keeps the reversal flag set for the remainder of the encounter.

6. Determine how Descend Descend Now can follow Vertical Speed Restricted.

This occurred due to the way aural advisories were enunciated. Because aural advisories take much longer to "display" than the visual advisories, it is possible for the RA to change while an aural advisory is still being enunciated. During particularly verbose advisories, it is even possible for more than one advisory to be issued while a previous advisory is still being enunciated. For this reason, the speech generators were programmed to only enunciate the most recent advisory issued, prohibiting intermediate, but not the current, aural advisory from being issued.

In this particular case, while the "Vertical Speed Restricted, Vertical Speed Restricted" advisory was being enunciated, a Climb advisory was issued. However, before the Vertical Speed Restricted, Vertical Speed Restricted enunciation was completed, the Descend Reversal advisory was also issued. Both of these advisories were displayed on the IVSI, but by the time the aural generator was finished enunciating the first advisory, the Climb advisory was no longer current and only the "Descend Descend Now" advisory was enunciated.

Discussions about this problem were included in meetings of both the RTCA and the Air Transport Association (ATA). Both groups agreed that the advisories need to be interrupted to limit this problem. The ATA now advises that advisory enunciations which are not current be interrupted, allowing the current advisory to be enunciated. While there is no such MOPS or FAA requirement, all production TCAS-II units do interrupt outdated advisories.

There are requirements for minimum advisory length, however. An advisory is required to be posted for at least 5s, unless it is interrupted by a higher priority advisory, or a multiaircraft or

descend inhibit situation exists. This 5s is sufficient time to enunciate any aural advisory. This requirement effectively ensures that weakening advisories will be accompanied by the proper aural enunciation, but still allows strengthening advisories to lead their aural enunciations.

7. Determine how aural advisories can be issued without the IVSI lights being lit.

See item 6.

8. Aural advisories must always agree with IVSI lights. If the IVSI lights indicate a new advisory, the aural must be interrupted at the instant the lights change.

See item 6. Note that current TCAS requirements still allow the IVSI lights to differ from the aural enunciation.

9. TCAS users must be made aware that intensive training regarding increases and reversals will be required to avoid loss of pilot confidence in the system.

This training should be included in all airline TCAS training programs.

10. Determine why Run 4 issued a "Descend Descend Descend" after a "Climb Climb Climb" instead of issuing a "Descend Descend Now."

See items 5 and 6. In this particular case, the Descend Reversal was issued while the Climb Climb Climb was being enunciated. By the time the aural generator was ready for the next advisory, the display logic had sensed the clearing of the reversal flag and issued a Descend advisory. The Descend advisory was then the current advisory and was enunciated.

CONCLUSIONS

SUMMARY OF RESULTS.

ACCOMPLISHMENT OF THE FLIGHT TEST PLAN OBJECTIVES. The two main objectives of the flight test plan were to evaluate the technical performance of the Minimum Operational Performance Standards (MOPS) version 6 logic under actual flight conditions, and to determine pilot acceptance of the escape maneuvers introduced by the new logic. These objectives were accomplished by designing aircraft encounters which stressed the new areas of the logic, and by performing these encounters with both Federal Aviation Administration(FAA) test pilots and aircraft industry pilots.

ENCOUNTER DESIGN. The design of the encounters was accomplished through analysis of the Traffic Alert and Collision Avoidance System TCAS)-II Change 6 logic and computer simulations. Encounters which stress the new features of the Change 6 logic are not easily generated or executed. However, the encounters in their final form as included

in appendix A do achieve the desired goals with a high rate of success.

Comparison of the simulated results with the actual flight data reveals that the computer simulations did provide accurate analysis of the TCAS performance, pilot and aircraft performance, altitude deviations as a result of the TCAS maneuvers, and altitude separation at closest point of approach (CPA).

Run 12, which only produced an INCREASE advisory once in the flight tests, was the only encounter which did not exercise the expected area of the logic. This variation was traced to a disparity between the actual flight data and the computer simulation of the target aircraft flightpath. (This disparity occurs only in the parallel/overtake simulation modeling.) Nevertheless, the encounter provided an interesting encounter for the pilot evaluation phase of the testing, since it presented the pilots with a long resolution (RA) sequence and an unseen target. This run also generated the longest and most distracting aural advisory sequences.

TECHNICAL PERFORMANCE OF THE LOGIC. The flight tests provided a broader range of logic tests than might be expected by the planned encounters. This was due to the imprecise nature of flight testing. The encounters can never be set up exactly as specified on the drawings, and the pilot response times and actions vary from run to run. Even with these variations, each encounter flown did produce adequate vertical separations at CPA (see table D-5, appendix D).

The altitude deviations were usually well under 1000 feet (ft) (see table D-5, appendix D). The altitude deviations for the REVERSAL RAs were particularly small. The altitude deviations for the INCREASE advisories tended to be quite large, however, often exceeding 1000 ft. These encounters involved outrunning maneuvering target aircraft while avoiding an altitude crossing maneuver. It should be noted that these high deviation TCAS maneuvers are less vulnerable than altitude crossing advisories to thwarting by further maneuvers of the target airplane. It should also be noted that these are low probability encounters.

The altitude deviations for run 12 were also very large. This encounter, as the other INCREASE RA encounters, requires the target aircraft to continue its climb or descent for a long period. Again, it should be noted that this is a low probability encounter.

The pilot briefing before each test flight included instruction on expected response times to the advisories, expected pilot response (i.e., acceleration and vertical rates), and explanation of each encounter and the expected advisories. These instructions were given both to train the pilot in the proper response to TCAS advisories, and to encourage the pilots to fly the encounters as accurately as possible to exercise the desired TCAS logic. The pilots also reviewed each encounter just before its execution.

While the pilots may not have received the advisories as simulated, they did expect advisories. As such, pilot response times and performance were probably more accurate, generally, than would be expected under normal TCAS operation. These factors may have affected the altitude deviations and distances at CPA. However, these expectations also led to sluggish responses and complaints about system performance when the system chose advisories different from those in the encounter description.

High resolution pilot response time data were not collected due to the unavailability of the necessary recording equipment, although this data recording was specified in the test plan. The prior knowledge by the pilots of the encounter and the advisories would probably have made any response time data incomparable with normal TCAS operational flight response times.

The performance of the logic was questioned by the pilots twice during the execution of the flight tests. Analysis of the data showed that the TCAS logic worked properly and as designed. The peculiarities of these encounters were due to sluggish pilot response to the advisories.

The TCAS logic operated well, although not as expected by the pilot, in both of these questioned encounters. Pilot reluctance to follow the advisories in the first case resulted in low separation. In the second case, the pilot reluctance resulted in the issue of a different advisory.

The logic performance was questioned several other times during the pilot evaluation flights. Most of these questions were revoked by the pilot when the encounter geometry was more thoroughly explained. The remaining questions were included in the "items which need to be addressed" list compiled by Ross Beins during the pilot debriefings. Most of those items were incorporated into the final Change 6 design.

PILOT ACCEPTANCE OF THE MANEUVERS. The pilots did have questions about the performance of the TCAS logic, many of which were based on their perceptions of the encounter geometry. However, there were no pilot complaints about their ability to perform the new increase rate and reverse sense advisories, or the use of these advisories in these encounters. None of the pilots felt that following the new advisories made the situation more dangerous, that the new advisories were inappropriate, or that another advisory would have been preferred.

The pilots did express some concern with the altitude deviations created when following the advisories. These concerns ranged from those who did not want to change their altitude for any reason to those who were concerned only about crossing other flight levels during the increase rate outrun encounters (encounters 7, 8, and 12).

The responses to the pilot questions revealed that the pilots generally felt that their workload during the encounters was the same or slightly reduced with the aid of TCAS.

CHANGES TO THE FEBRUARY 1989 LOGIC AS A RESULT OF THE FLIGHT TESTS.

There were several changes made to the February Change 6 logic which resulted from pilot comments and TCAS performance during the flight tests. Most of the comments were in reference to the aural advisories generated by TCAS.

Pilot complaints that advisories don't match the Instantaneous Vertical Speed Indicator (IVSI) lights have been addressed through the Air Transport Association (ATA), which advises that outdated aural alerts be terminated. While there is no such MOPS or FAA requirement, all production TCAS-II units do interrupt outdated advisories.

Pilot complaints of excessive aural advisories have been addressed by keeping the present aural advisory posted until the RA is actually changed (i.e., previously, the aural alert would change from "Climb" to "Maintain Vertical Speed" when the proper climb rate was reached). Advisory changes may still be brought on by either sluggish or overzealous performance by the pilot. Airline crew training and familiarity with the system should eliminate these problems.

Many pilots complained about the track drops near CPA and the lack of the Clear of Conflict enunciation at the end of an encounter. Both manufacturers improved the hardware and software in their surveillance subsystems to eliminate these problems. These problems and solutions are not part of the TCAS logic.

The erroneous run 17 (see appendix C) produced several questions about the TCAS logic time threshold for advisory reversals and the firmness requirement for INCREASE advisories. These concerns are not regarded as safety issues, and have been submitted for investigation to The MITRE Corporation through Change Request Form (CRF) No. 29.

EXPECTED CHANGES TO TESTS AND RESULTS USING THE SEPTEMBER 1989 LOGIC.

Repeating the simulations of the flight test encounters using the final version of Change 6 altered some of the results. The changes have little or no effect on the majority of the encounters. The remaining encounters are affected by either the lowering of the 900 ft rule to the 600 ft rule, or the alteration of the Descend and Increase Descend inhibit altitudes. Several encounters required modification to continue to test the desired areas of the logic, and these modified encounters are included in appendix B.

The altitude difference at the time of the expected advisory issuance is over 600 ft in several of the original encounters. These advisories will be suppressed by the 600 ft rule. In some of these encounters, advisories will not be generated at all as the delay allows the logic to choose a completely different solution based on later information. As such, the relative altitudes of several encounters have been modified for inclusion in appendix B.

The Descend and Increase Descend inhibit test encounters were designed for the specific altitudes which trigger these inhibits. The new

altitudes for these inhibits will alter the chosen advisories for the original encounters. As such, the base altitudes of these encounters have been changed for inclusion in appendix B.

It should be noted that an error in the final logic was discovered while revising run 16 for the lower Increase Descend altitude of the final Change 6 logic. If a DESCEND advisory is already posted, TCAS will not inhibit the advisory if true tau (range/range rate) is less than 2.5 seconds when the airplane descends through the descend inhibit altitude. This error has been reported to The MITRE Corporation through Problem/Trouble Report (PTR) No. 53. The revised run 16 in appendix B demonstrates this problem.

All the replacement encounters in appendix B should test the areas in the revised logic which correspond with the logic tested in the original encounters.

The pilots should notice a significant improvement in the aural alert performance. The surveillance improvements will eliminate the extraneous TRAFFIC alerts near CPA, and replace them with the expected CLEAR OF CONFLICT advisories. The MAINTAIN VERTICAL SPEED advisories will not be issued upon attaining the desired vertical rate after a CLIMB or DESCEND advisory. Cutting off the advisories should prevent most occurrences of missed aural advisories, and keep the aural alerts and IVSI indications more synchronized.

Overall, the final Change 6 (September 1989) logic should significantly address most pilot complaints about incorrect and excessive aural enunciations, and eliminate some advisories with large altitude separations.

APPENDIX A

DETAILED DESCRIPTIONS OF THE ENCOUNTERS AS FLOWN

OVERVIEW

The full encounter descriptions, including drawings and the associated logic tests, are contained in this appendix. These descriptions provide all information needed by the pilots to perform the desired encounters. Information not provided may be chosen by the pilots for their convenience.

Each encounter states:

The equipage of the two aircraft.

A brief description of the logic test involved and expected results.

The slant ranges of any range sensitive maneuvers and significant events during the encounters.

The closing speed of the encounter (true airspeed).

The starting separation for the encounter.

The expected advisories from the Traffic Alert and Collision Avoidance System (TCAS) unit or units.

Additionally, each encounter includes a side view drawing of the run to scale. The altitude scale appears on the left side of the drawing and usually indicates relative altitudes (the only absolute altitudes are included in runs 15 through 17). All runs besides runs 15 through 17 are to be performed above 10,000 ft (feet).

The other scale on all runs is a time scale. These are either based on the time from PLANE 1 traffic alert (TA), or the PLANE 1 resolution advisory (RA). They are actually two scales which meet in the center (at closest point of approach (CPA)). Runs 11 and 12 each include two drawings, one with the time scales meeting at CPA, and a second with parallel time scales to show the relative motion of the planes. The PLANE 2 scale is stretched to show PLANE 2 overtaking PLANE 1.

PILOT DELAY AND ACCELERATIONS

There are two types of maneuvers included in the encounter drawings: Response to TCAS maneuvers, and encounter geometry maneuvers. The expected results and drawings for each encounter include delays for pilot response to the TCAS advisories, and the aircraft acceleration times.

The expected pilot delay times and aircraft accelerations for responding to TCAS advisories are as follows:

	Initial RA	**Subsequent RAs**
Pilot Delay	5 seconds	2.5 seconds

	Initial RA	**Reversal**	**Increase Rate**
Acceleration	.25 g	.35 g	.35 g
Vertical Rate	1500 fpm	1500 fpm	2500 fpm

Note that the acceleration rate for an Increase Rate RA is not specified in the logic. The .35 g acceleration was used in the computer simulations to prepare the encounters, and should be followed.

There is no pilot delay expected for the encounter geometry maneuvers, since the pilot should be prepared to start these maneuvers at the indicated times. All encounter geometry maneuvers should use an acceleration of .25 g to the specified vertical rate unless noted otherwise. (These maneuvers are usually indicated on the encounter descriptions with the word "begin" followed by a maneuvering instruction.) Runs 13 and 14 specify geometry maneuvers at 1/3 g.

Since the encounter geometry maneuvers are often based on the time of a TCAS advisory in the other plane, the pilot of the TCAS plane should inform the pilot of the non-TCAS plane of this advisory in time for this maneuver to take place. This may be accomplished either by informing the non-TCAS pilot at the time of the advisory and letting him (or someone else with him in the cockpit) count the delay time before maneuvering, or warning the non-TCAS pilot of the impending start-of-maneuver time and signaling him to start at the proper time.

Some of the encounters were modified from those contained in the Validation Flight Test Plan for TCAS-II Logic Changes (MOPS Change 6). (See Modification to Scenarios During the Flight Test Period above.) These changes are summarized in table A-1.

TABLE A-1. SUMMARY OF MODIFICATIONS TO THE ENCOUNTERS DURING THE FLIGHT TEST PERIOD

Runs 4, 9, and 10:

The vertical rate of the maneuver was increased from 1750 to 2000 fpm. This change allowed the tracker to recognize the maneuver sooner.

Runs 5 and 6:

The initial altitude separation was increased by 300 ft to allow each aircraft a larger margin of vertical maneuverability.

Run 14:

The vertical rate was decreased from 2500 to 2000 fpm, and the intruder rate slacken at 1/3 g was changed to a level-off. These new maneuvers were easier to accomplish.

Run 12:

This encounter failed to produce the same results as the computer simulation. This failure was traced to a difference in the simulated target tracking data from the actual flight paths. With the actual flightpath data, the planes were never projected to be within 200 ft, and an increase rate advisory was never issued.

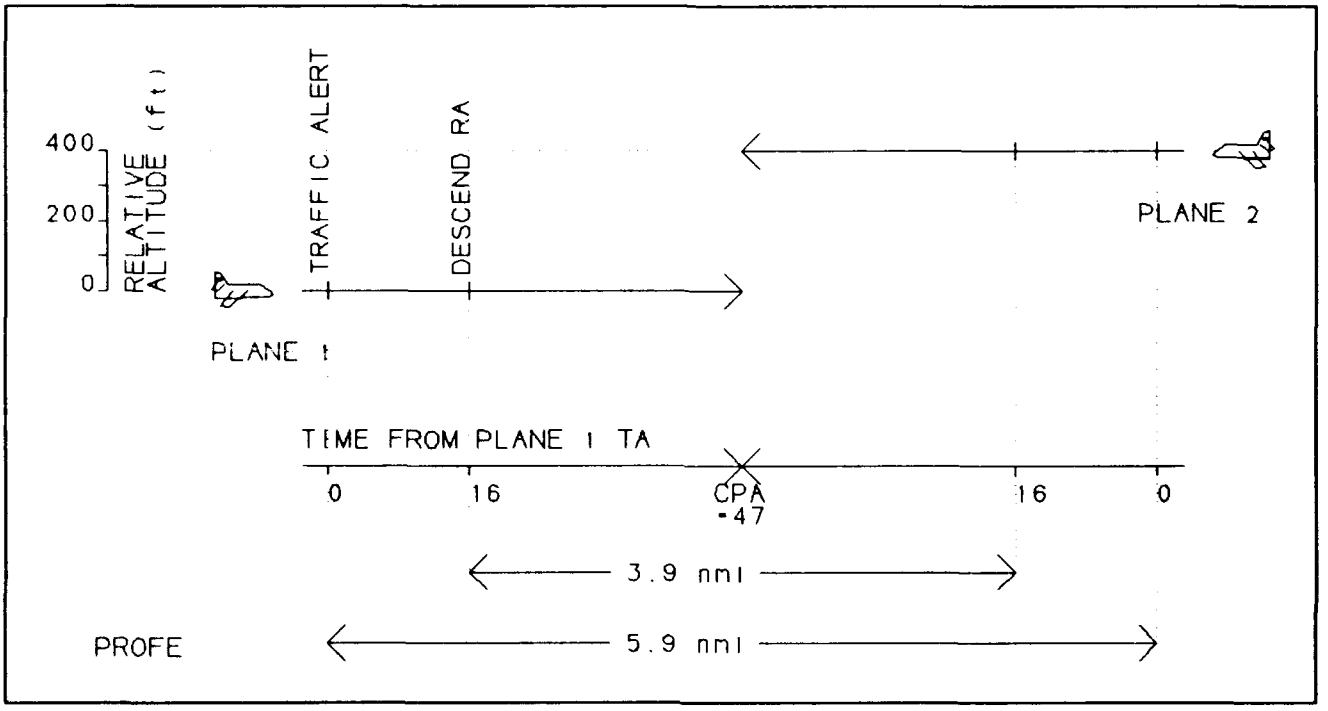
RUN 1

PLANE 1: TCAS

PLANE 2: MODE C

This run is a basic system test run.

The run is a simple TCAS to Mode C head-on encounter. The TCAS pilot will not follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

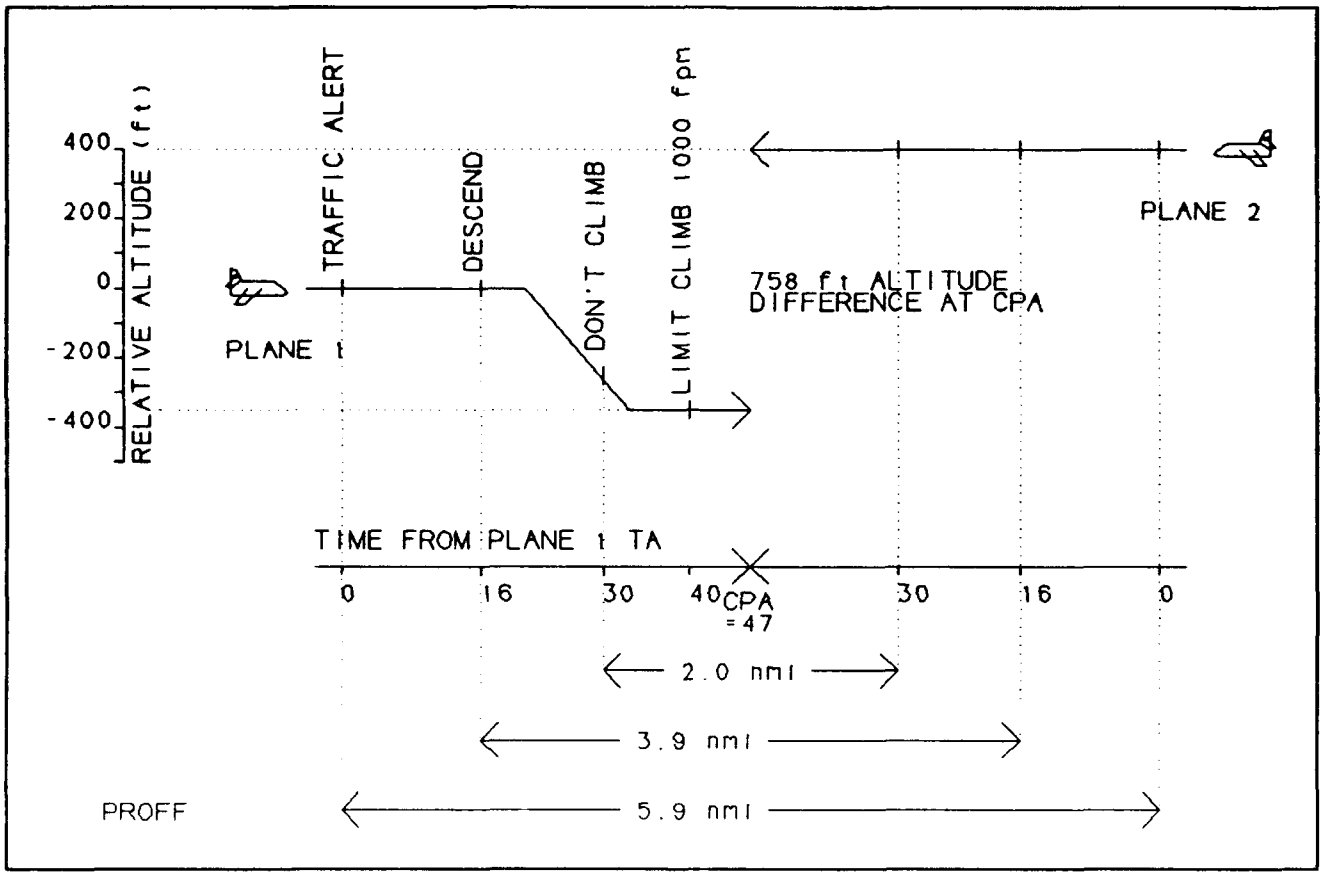
RUN 2

PLANE 1: TCAS

PLANE 2: MODE C

This run is a basic system test run.

The run is a simple TCAS to Mode C head-on encounter. The TCAS pilot will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

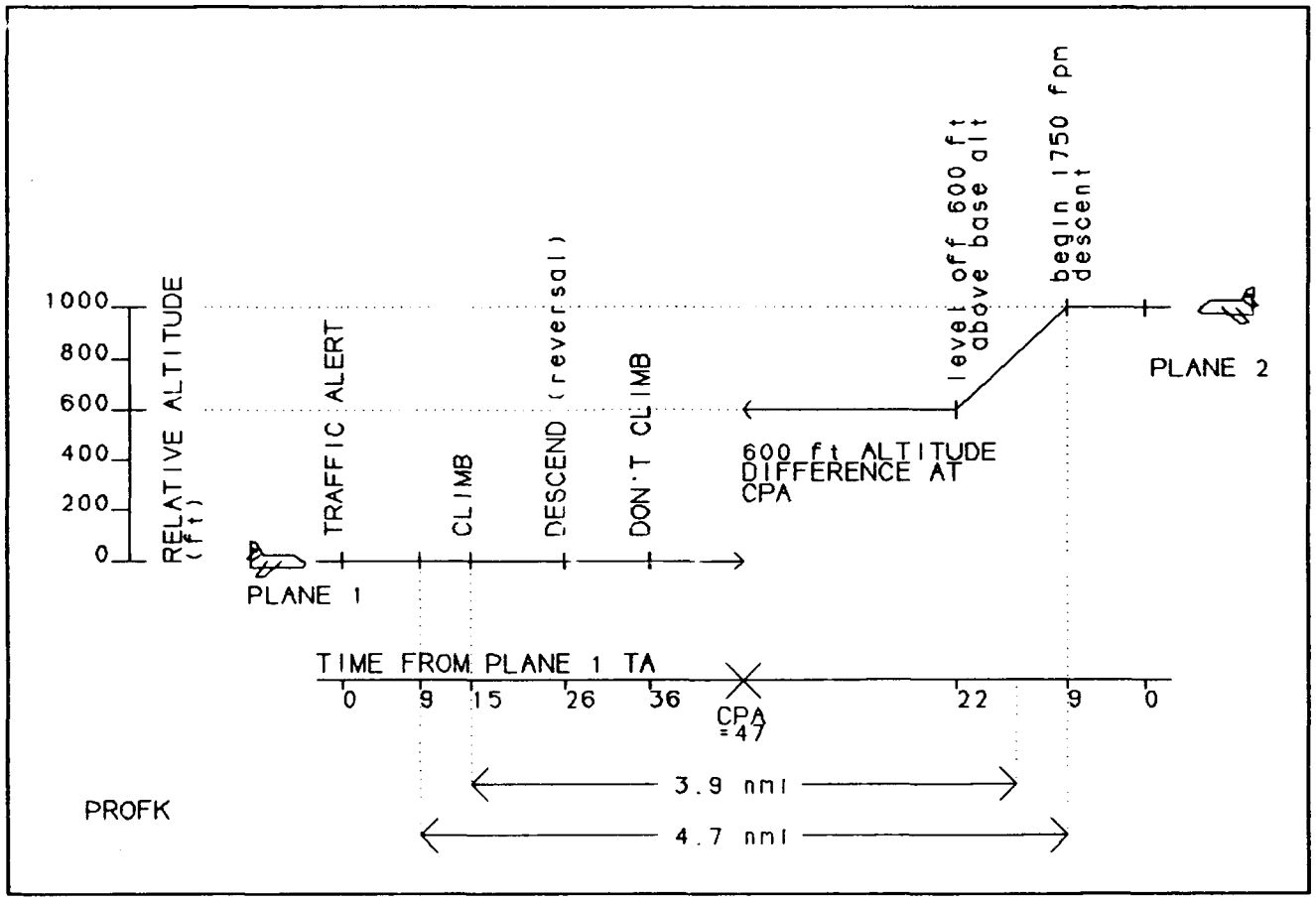
- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 3

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *RA REVERSAL DUE TO INTRUDER LEVEL-OFF* logic.

In this encounter PLANE 2 will start a 1750 fpm descent 9 seconds after PLANE 1 receives a **TRAFFIC ALERT**. PLANE 2 will then level off 600 ft above the base altitude. TCAS will issue a **CLIMB** advisory on the descending PLANE 2, followed by a **DESCEND REVERSAL** when the level-off is detected. The TCAS pilot will ignore the advisories.



ADDITIONAL FLIGHT INFORMATION:

- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

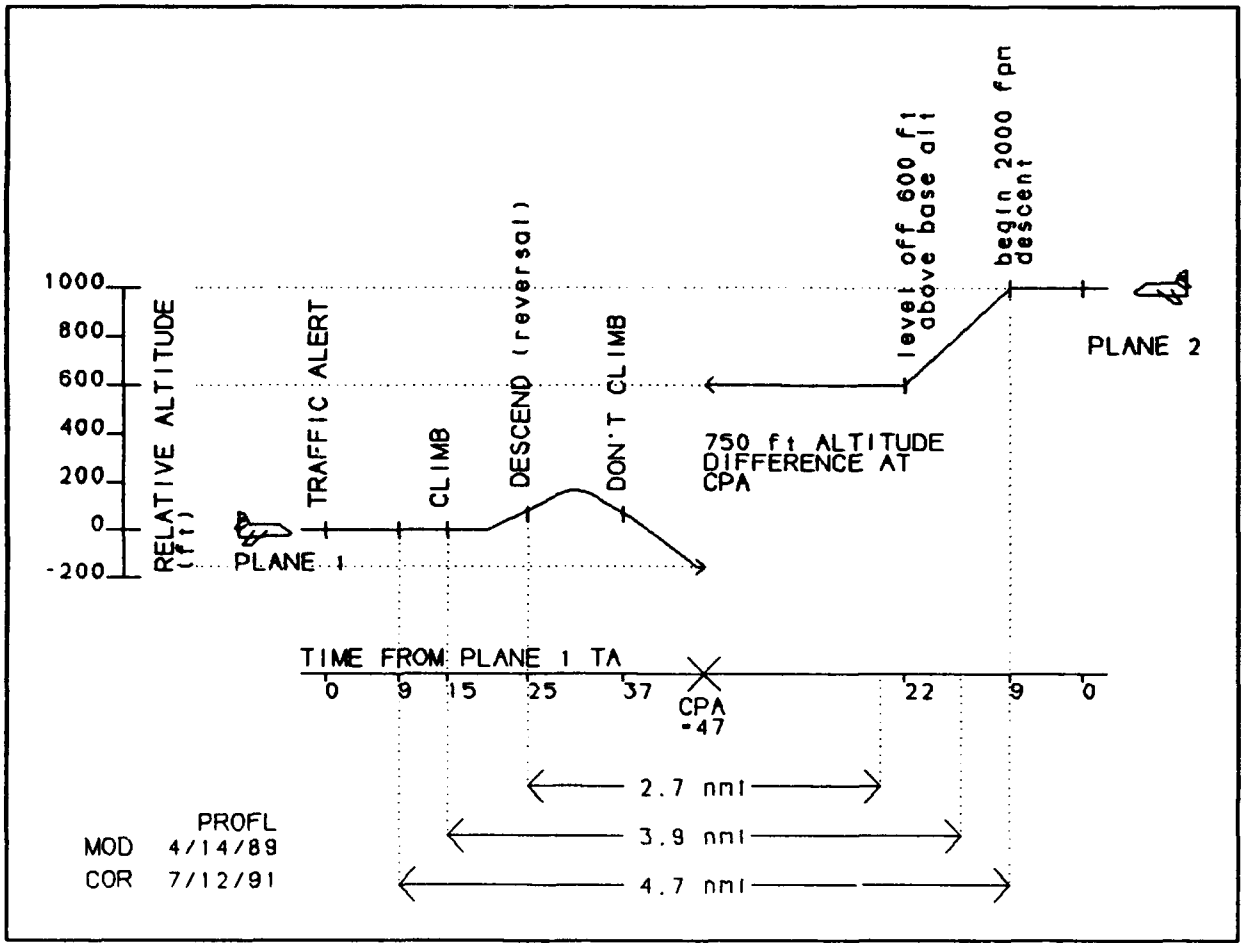
NOTE: The logic has been altered since the flight tests were performed. This encounter will not produce these results with the newer logic. An updated encounter is included in appendix B.

RUN 4

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *RA REVERSAL DUE TO INTRUDER LEVEL-OFF* logic.

In this encounter, PLANE 2 will start a 2000 fpm descent 9 seconds after PLANE 1 receives a **TRAFFIC ALERT**. PLANE 2 will then level off 600 ft above the base altitude. TCAS will issue a **CLIMB** advisory on the descending PLANE 2, followed by a **DESCEND REVERSAL** when the level-off is detected. The TCAS pilot will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

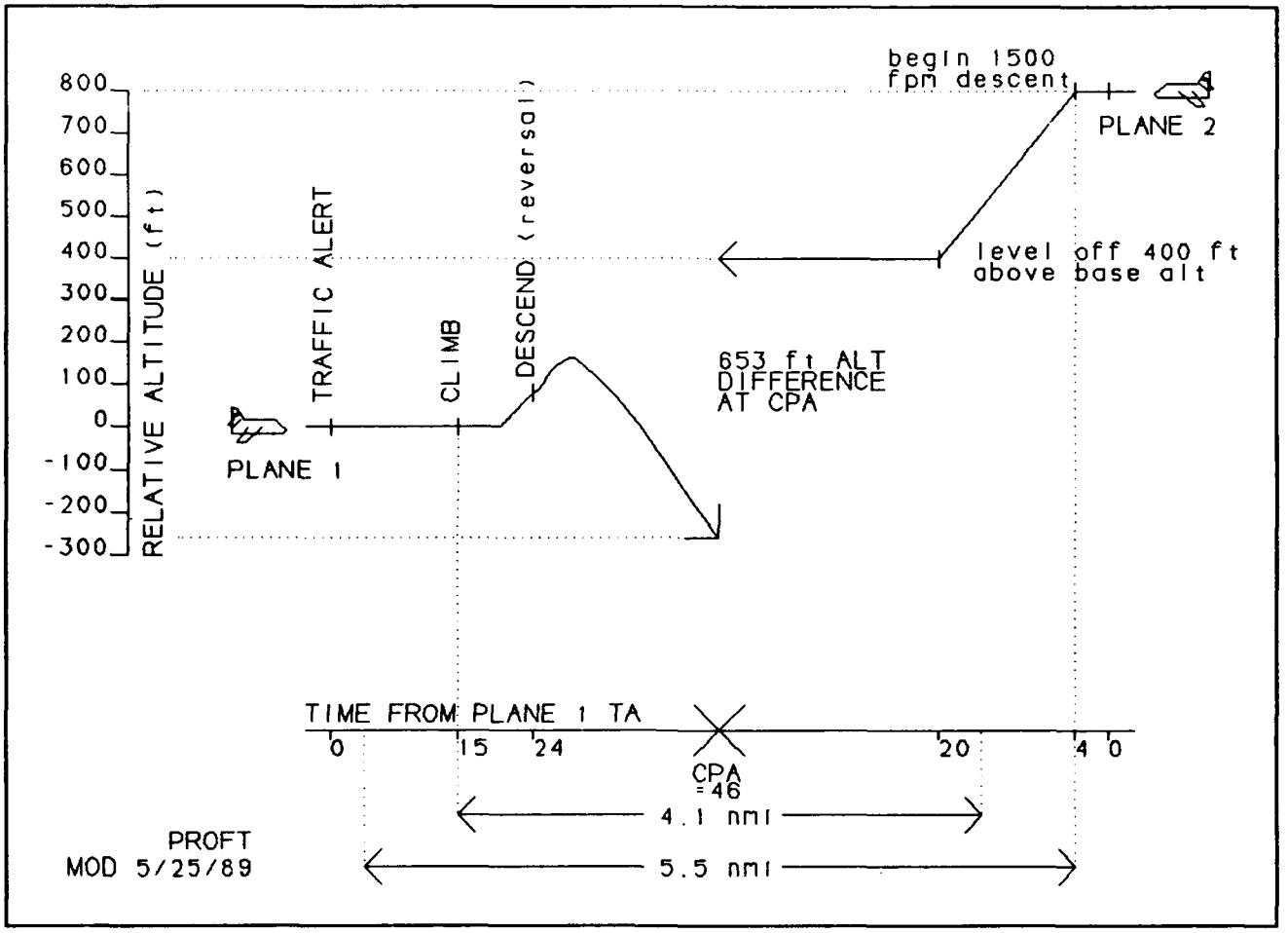
NOTE: The logic has been altered since the flight tests were performed. This encounter will not produce these results with the newer logic. An updated encounter is included in appendix B.

RUN 5

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *ADVISORY REVERSAL* logic.

This encounter is a vertical fake-out with PLANE 2 descending at 1500 fpm towards PLANE 1 shortly after the PLANE 1 TCAS issues a **TRAFFIC ALERT**. PLANE 2 begins to level-off 400 ft above the base altitude shortly after TCAS issues a **CLIMB** advisory. When TCAS detects the level-off, it issues a **DESCEND REVERSAL** advisory. *The TCAS pilot will follow the advisories.*



ADDITIONAL FLIGHT INFORMATION:

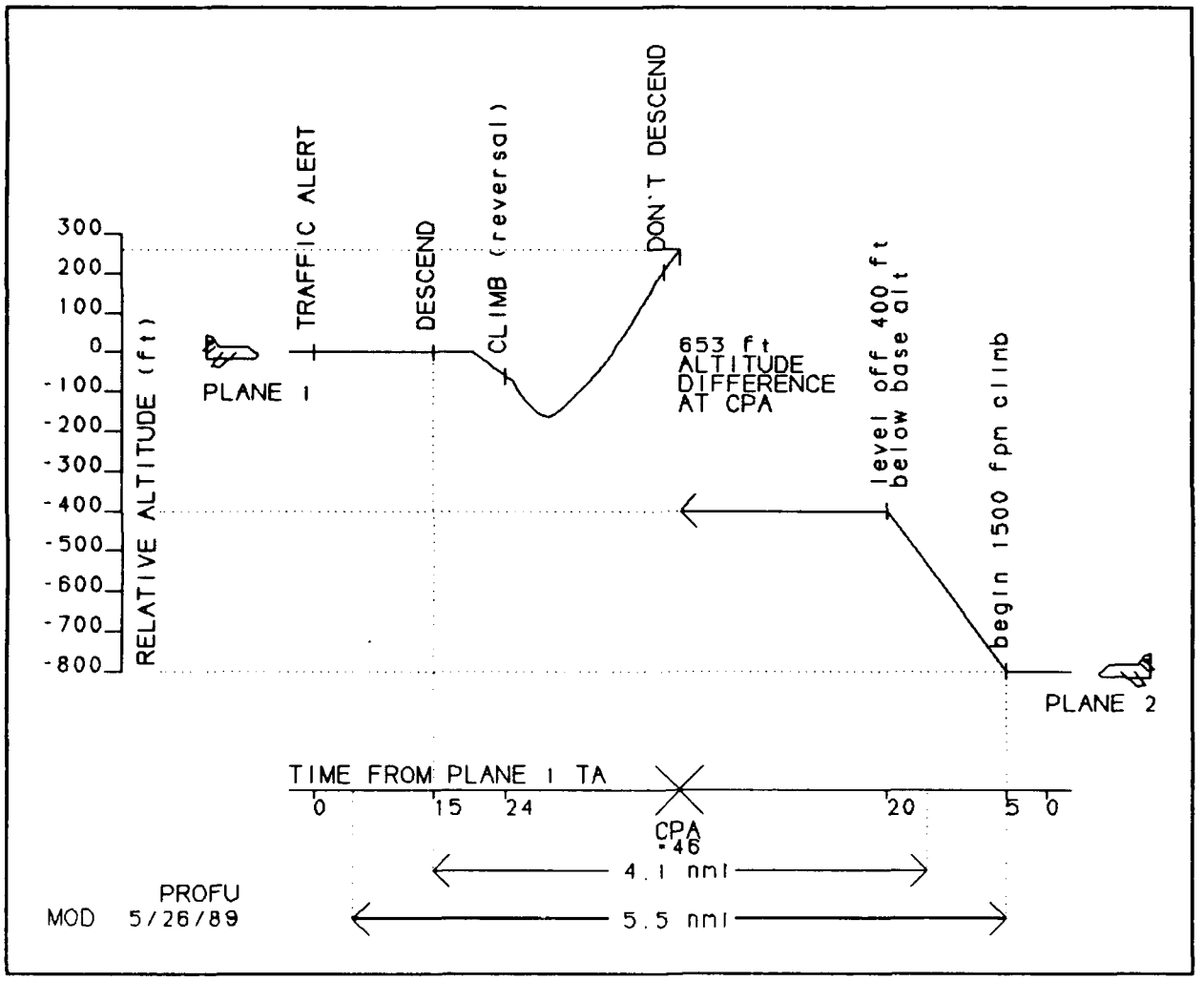
- Encounter closing speed is 480 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 6

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *ADVISORY REVERSAL* logic.

This encounter is a vertical fake-out with PLANE 2 climbing at 1500 fpm towards PLANE 1 shortly after the PLANE 1 TCAS issues a **TRAFFIC ALERT**. PLANE 2 begins to level-off 400 ft below the base altitude shortly after TCAS issues a **DESCEND** advisory. When TCAS detects the level-off, it issues a **CLIMB REVERSAL** advisory. The TCAS pilot will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

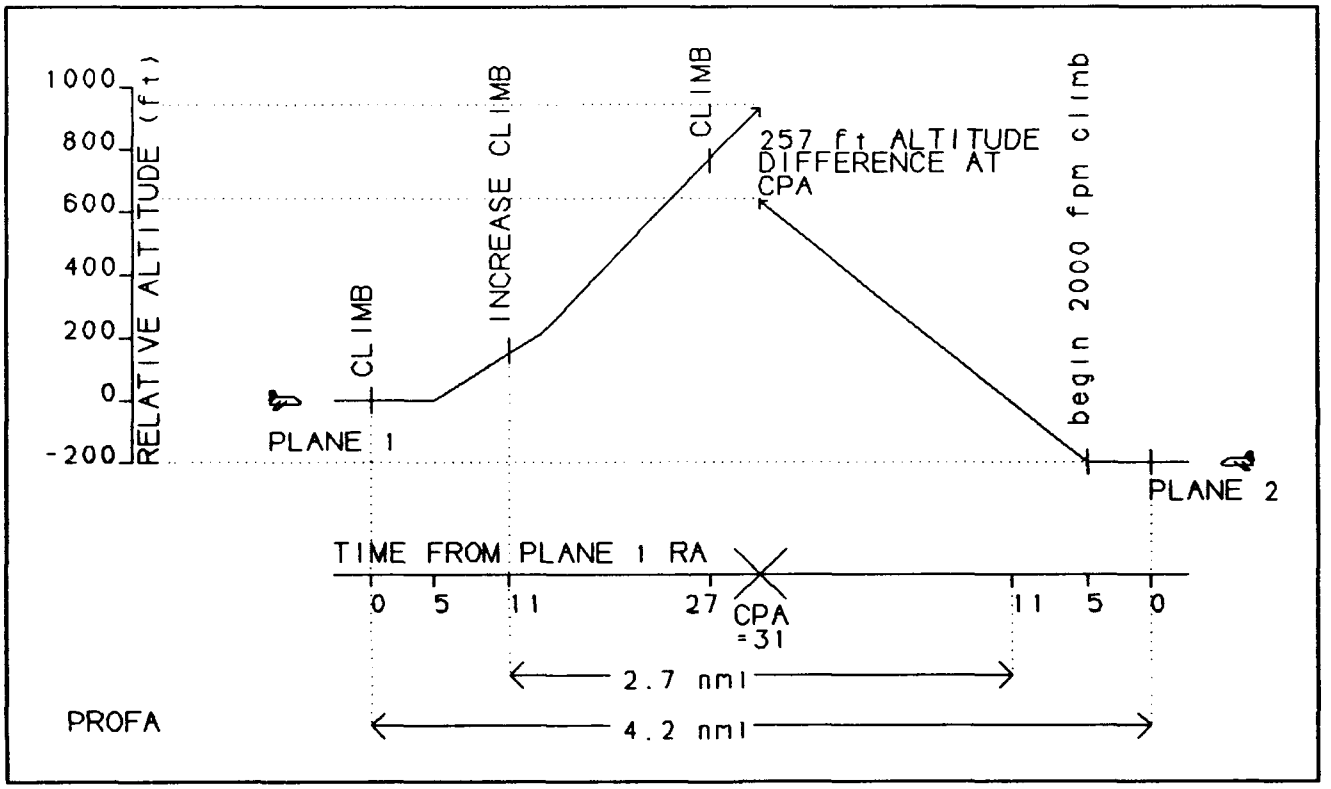
- Encounter closing speed is 480 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 7

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *INCREASE ADVISORY* logic.

This encounter is a simple head-on which will induce the PLANE 1 TCAS to issue a **CLIMB** advisory. The pilot of PLANE 2 will begin a 2000 fpm climb just as PLANE 1 begins its TCAS avoidance maneuver. The PLANE 1 TCAS will issue an **INCREASE CLIMB** advisory to outrun PLANE 2. The PLANE 1 pilot will follow all advisories.



ADDITIONAL FLIGHT INFORMATION:

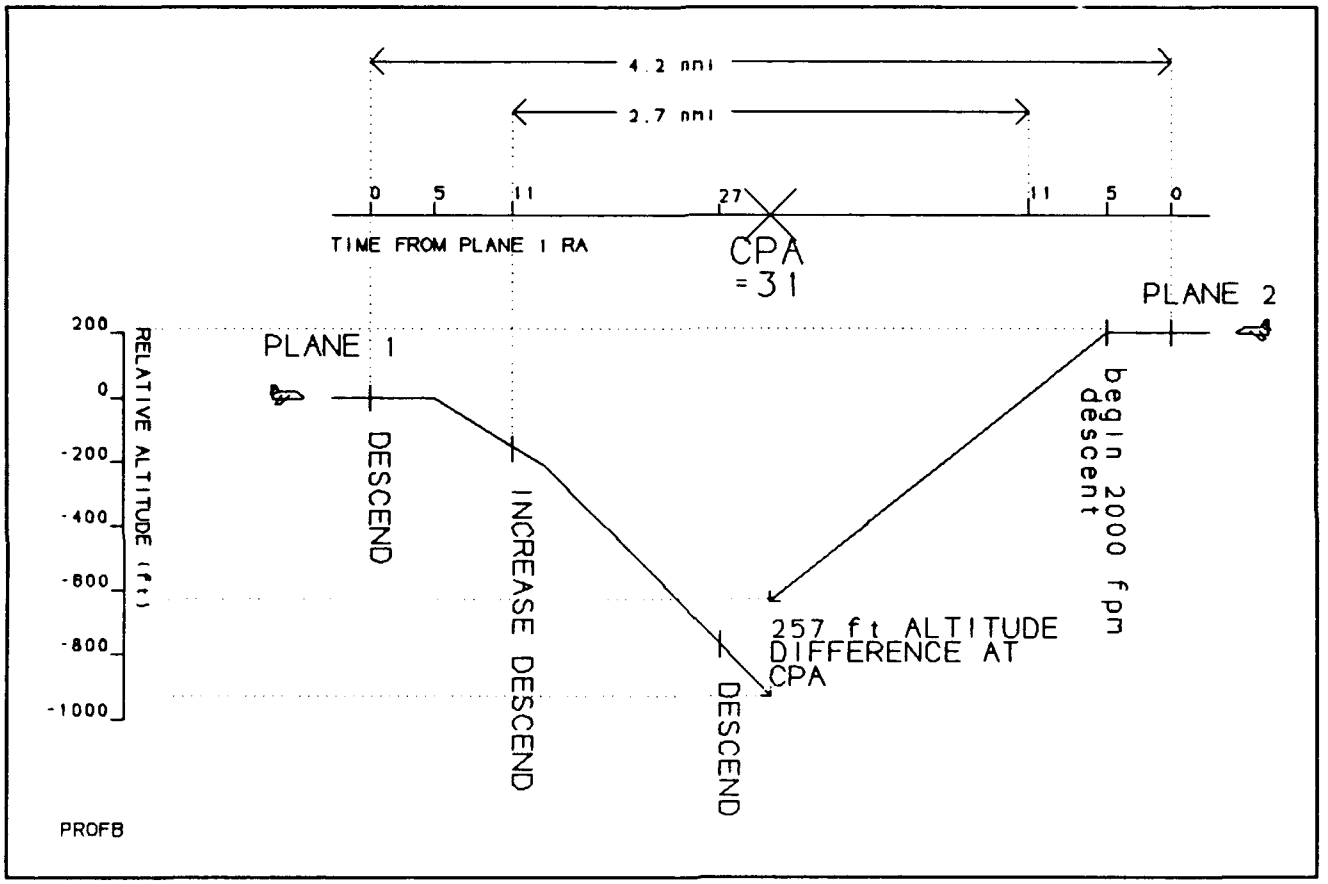
- PLANE 1 pilot will synchronize start of climb maneuver with PLANE 2.
- Encounter closing speed is 500 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 8

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *INCREASE ADVISORY* logic.

This encounter is a simple head-on which will induce the PLANE 1 TCAS to issue a **DESCEND** advisory. The pilot of PLANE 2 will begin a 2000 fpm descent just as PLANE 1 begins its TCAS avoidance maneuver. The PLANE 1 TCAS will issue an **INCREASE DESCEND** advisory to outrun PLANE 2. The PLANE 1 pilot will follow all advisories.



ADDITIONAL FLIGHT INFORMATION:

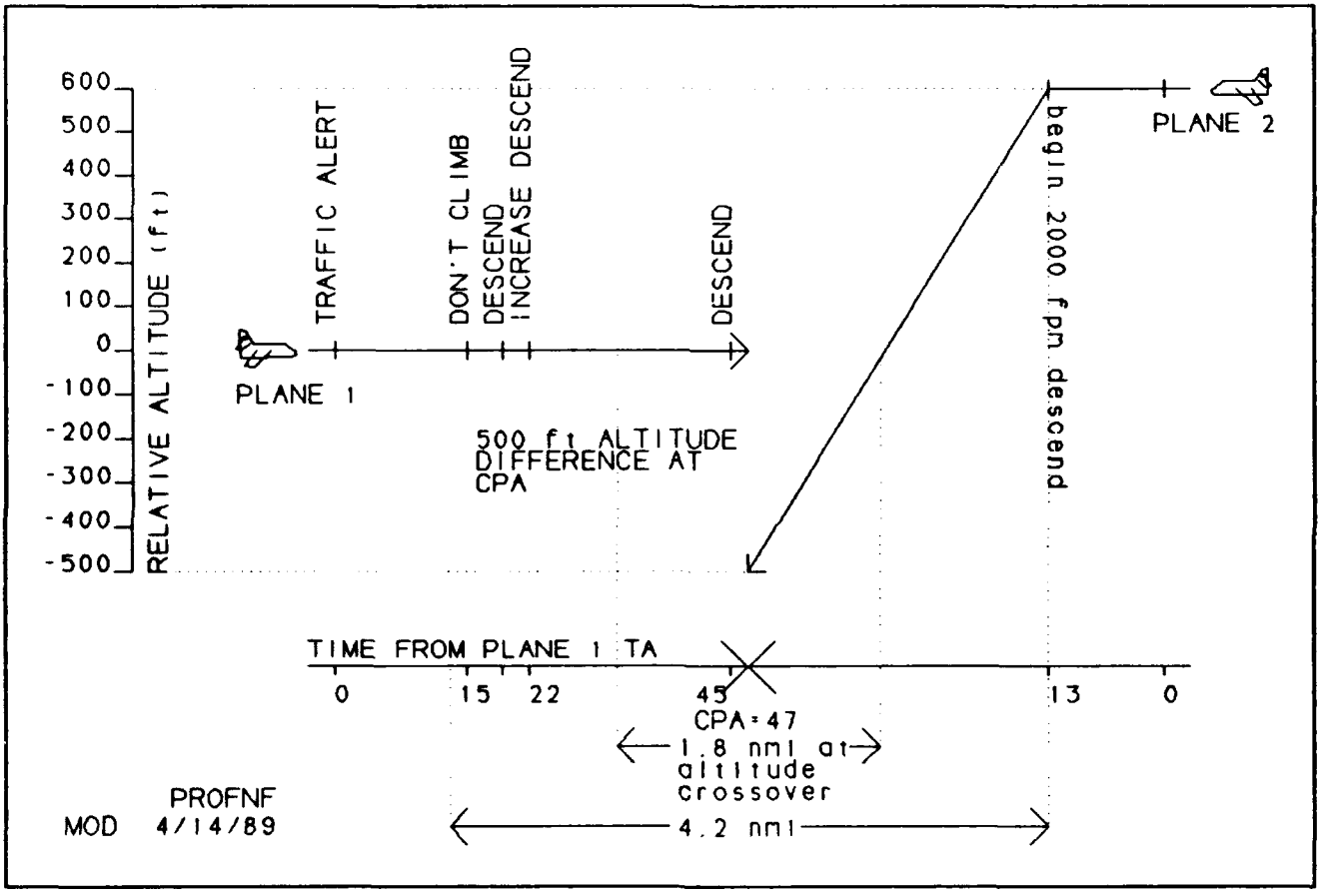
- PLANE 1 pilot will synchronize start of descend maneuver with PLANE 2.
- Encounter closing speed is 500 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 9

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *INCREASE ADVISORY* logic.

In this encounter, PLANE 2 will begin a 2000 fpm descend towards PLANE 1 just before the PLANE 1 TCAS issues a **DON'T CLIMB** advisory. When the TCAS detects that PLANE 2 is descending, it will issue a **DESCEND** advisory. An **INCREASE DESCEND** advisory will then be issued because of the high vertical rate of PLANE 2. The TCAS pilot will ignore all advisories.



ADDITIONAL FLIGHT INFORMATION:

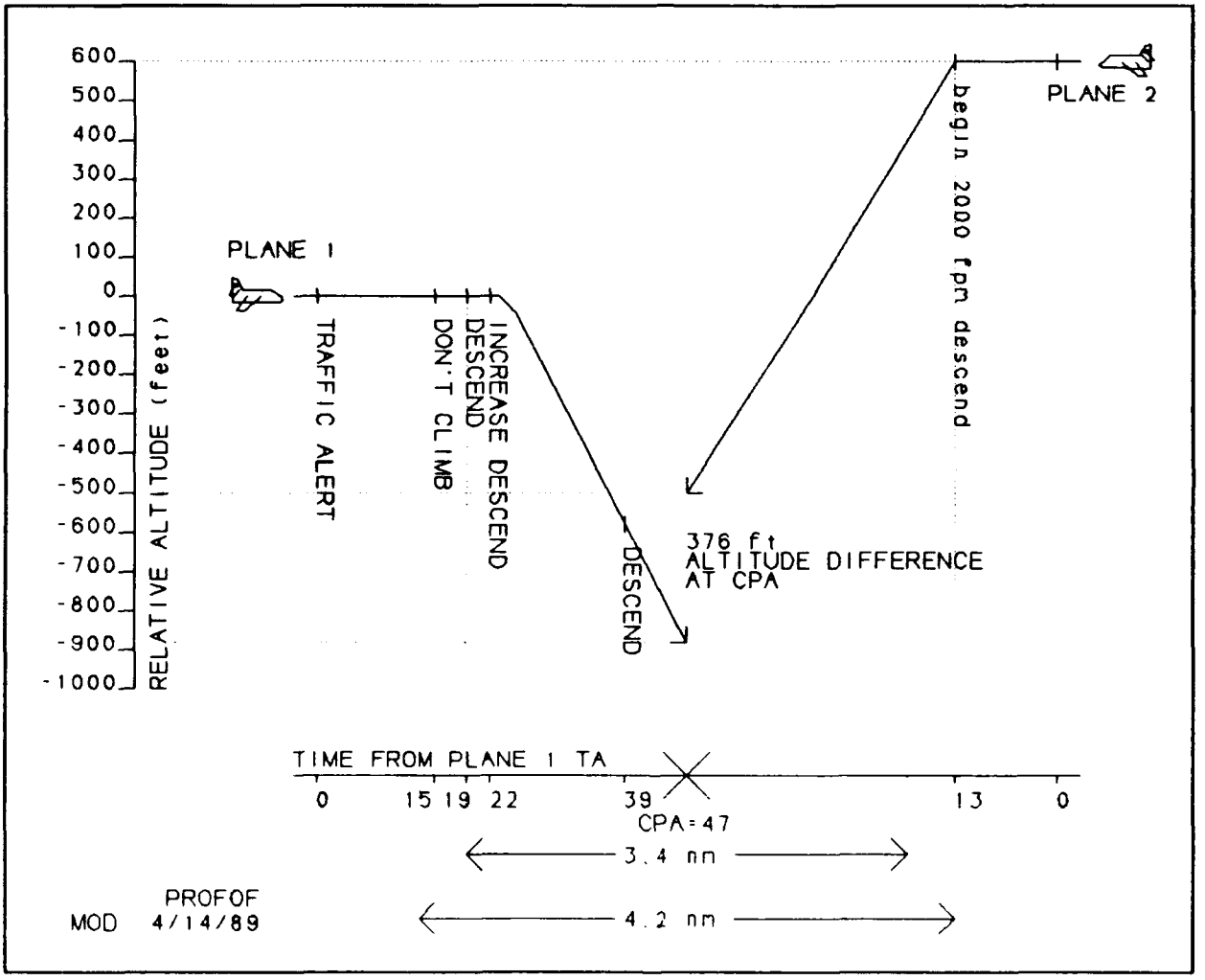
- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 10

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *INCREASE ADVISORY* logic.

In this encounter, PLANE 2 will begin a 2000 fpm descend towards PLANE 1 just before the PLANE 1 TCAS issues a **DON'T CLIMB** advisory. When the TCAS detects that PLANE 2 is descending, it will issue a **DESCEND** advisory. An **INCREASE DESCEND** advisory will then be issued because of the high vertical rate of PLANE 2. When TCAS determines that sufficient separation will be achieved, the advisory will downgrade to a **DESCEND**. The TCAS pilot will follow all advisories.



ADDITIONAL FLIGHT INFORMATION:

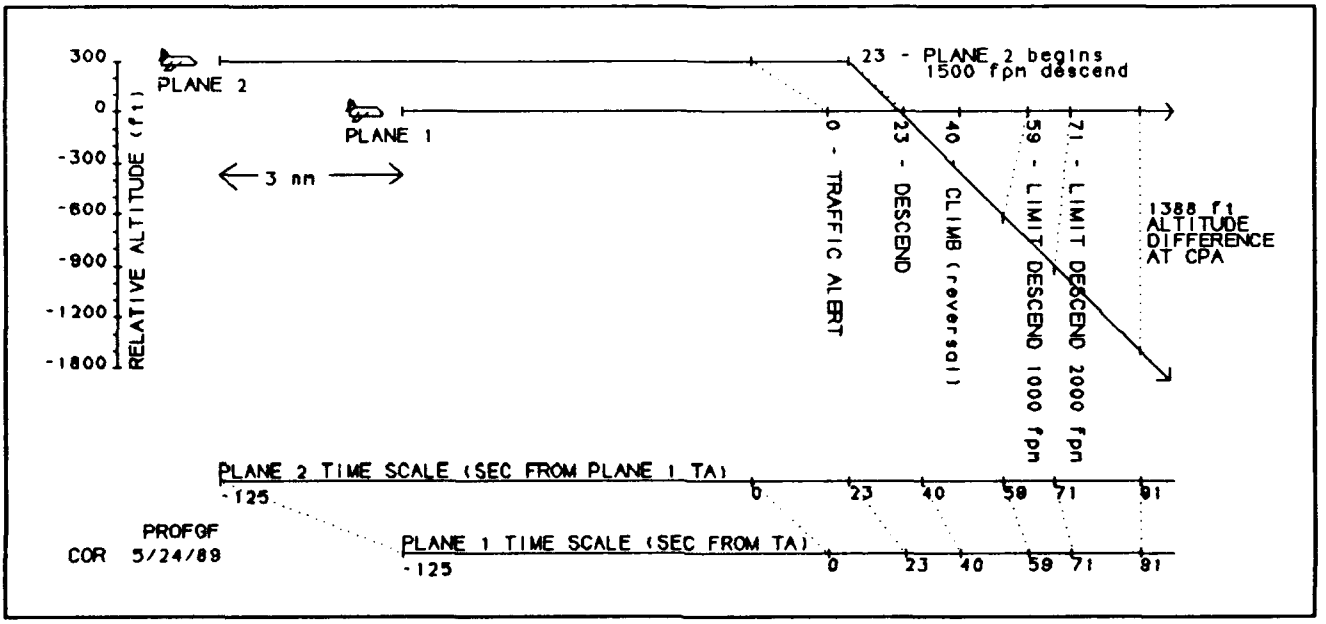
- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 11 1 of 2

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *SLOW OVERTAKE and ADVISORY REVERSAL* logic.

This encounter is a tail chase with PLANE 2 overtaking PLANE 1 at 50 knots. Twenty-three seconds after TCAS issues a **TRAFFIC ALERT**, PLANE 2 begins a 1500 fpm descent. PLANE 2 will cross PLANE 1's altitude about .9 nmi behind PLANE 1. The pilot will ignore the advisories.



ADDITIONAL FLIGHT INFORMATION:

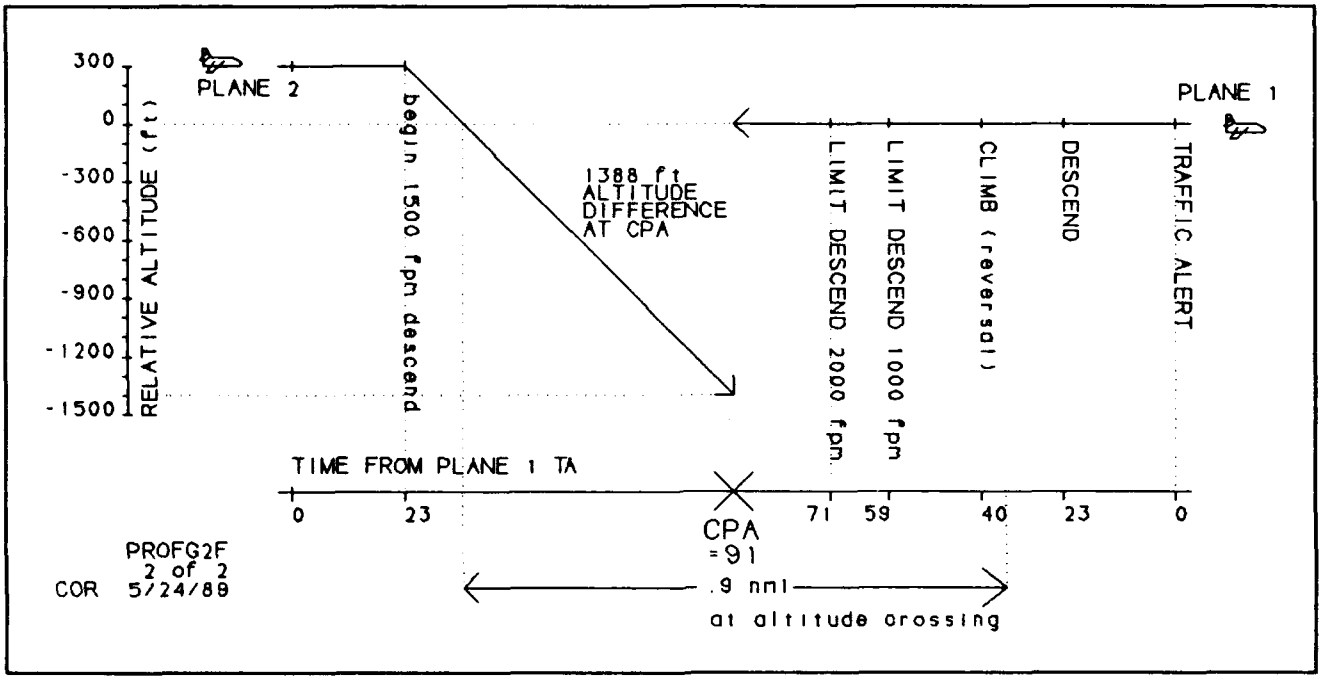
- Encounter closing speed is 50 kts.
- Encounter starting separation is 3 nmi.
- All altitudes are above 10,000 ft.

RUN 11 2 of 2

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *SLOW OVERTAKE and ADVISORY REVERSAL* logic.

This encounter is a tail chase with PLANE 2 overtaking PLANE 1 at 50 knots. Twenty-three seconds after TCAS issues a **TRAFFIC ALERT**, PLANE 2 begins a 1500 fpm descent. PLANE 2 will cross PLANE 1's altitude about .9 nmi behind PLANE 1. The pilot will ignore the advisories.



ADDITIONAL FLIGHT INFORMATION:

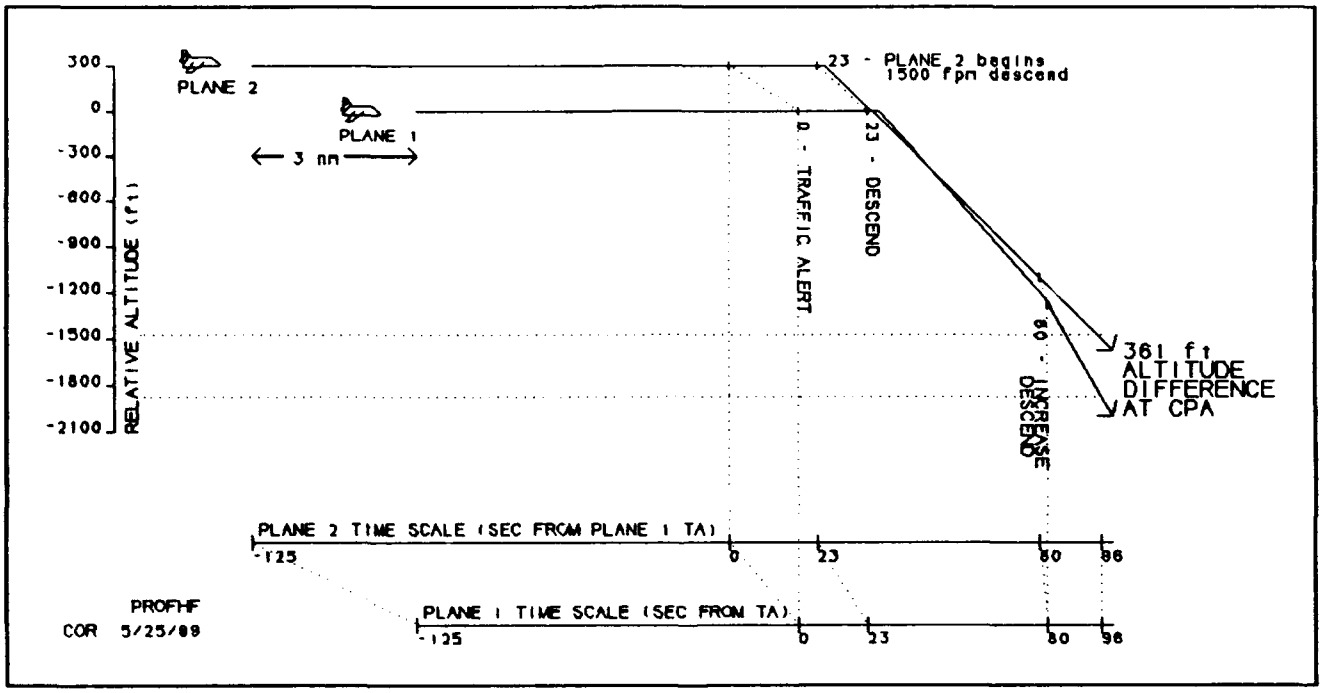
- Encounter closing speed is 50 kts.
- Encounter starting separation is 3 nmi.
- All altitudes are above 10,000 ft.

RUN 12 1 of 2

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *SLOW OVERTAKE and INCREASE ADVISORY* logic.

This encounter is a tail chase with PLANE 2 overtaking PLANE 1 at 50 knots. Twenty-three seconds after TCAS issues a **TRAFFIC ALERT**, PLANE 2 begins a 1500 fpm descent. The PLANE 1 TCAS will issue a **DESCEND** advisory to keep PLANE 1 below PLANE 2. PLANE 2 should pass over 350 ft above PLANE 1. The pilot will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

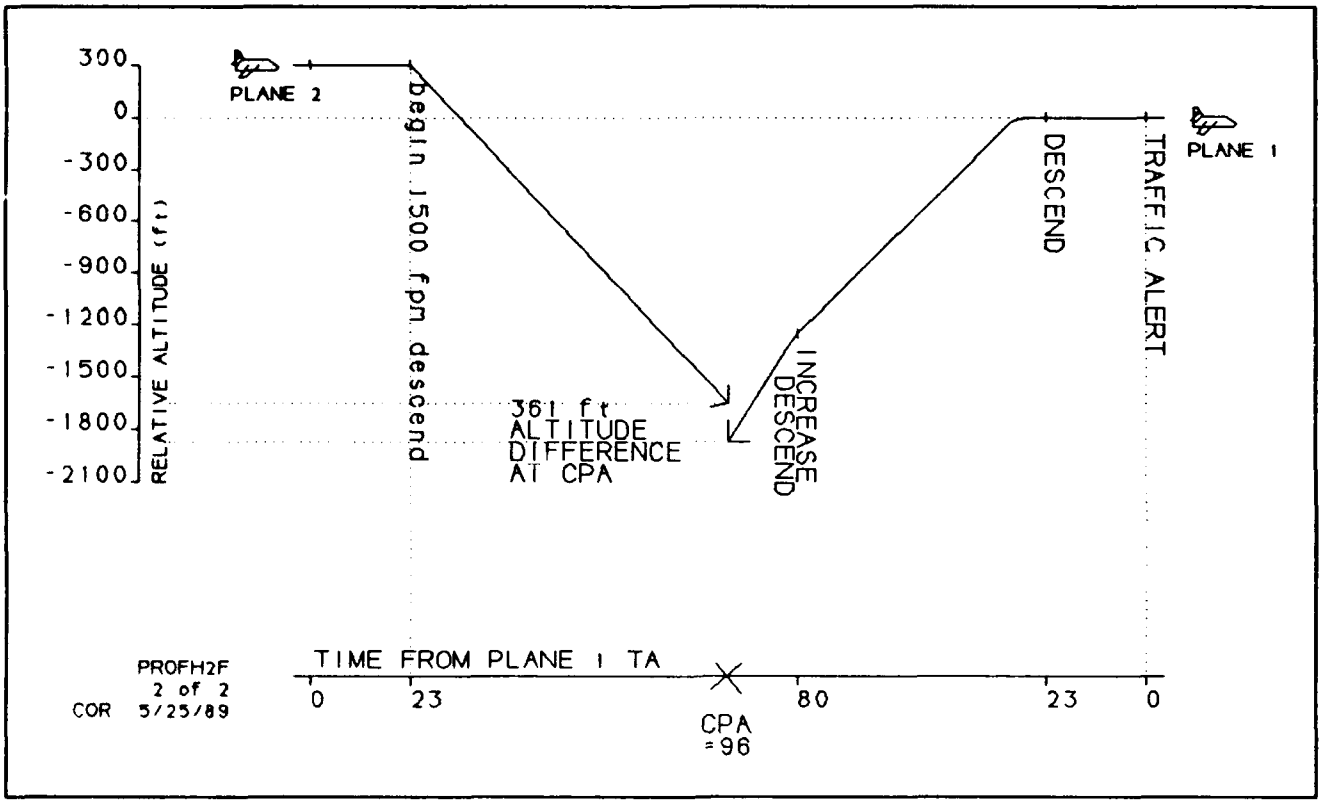
- Encounter closing speed is 50 kts.
- Encounter starting separation is 3 nmi.
- All altitudes are above 10,000 ft.

RUN 12 2 of 2

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *SLOW OVERTAKE and INCREASE ADVISORY* logic.

This encounter is a tail chase with PLANE 2 overtaking PLANE 1 at 50 knots. Twenty-three seconds after TCAS issues a **TRAFFIC ALERT**, PLANE 2 begins a 1500 fpm descent. The PLANE 1 TCAS will issue a **DESCEND** advisory to keep PLANE 1 below PLANE 2. PLANE 2 should pass over 350 ft above PLANE 1. The pilot will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

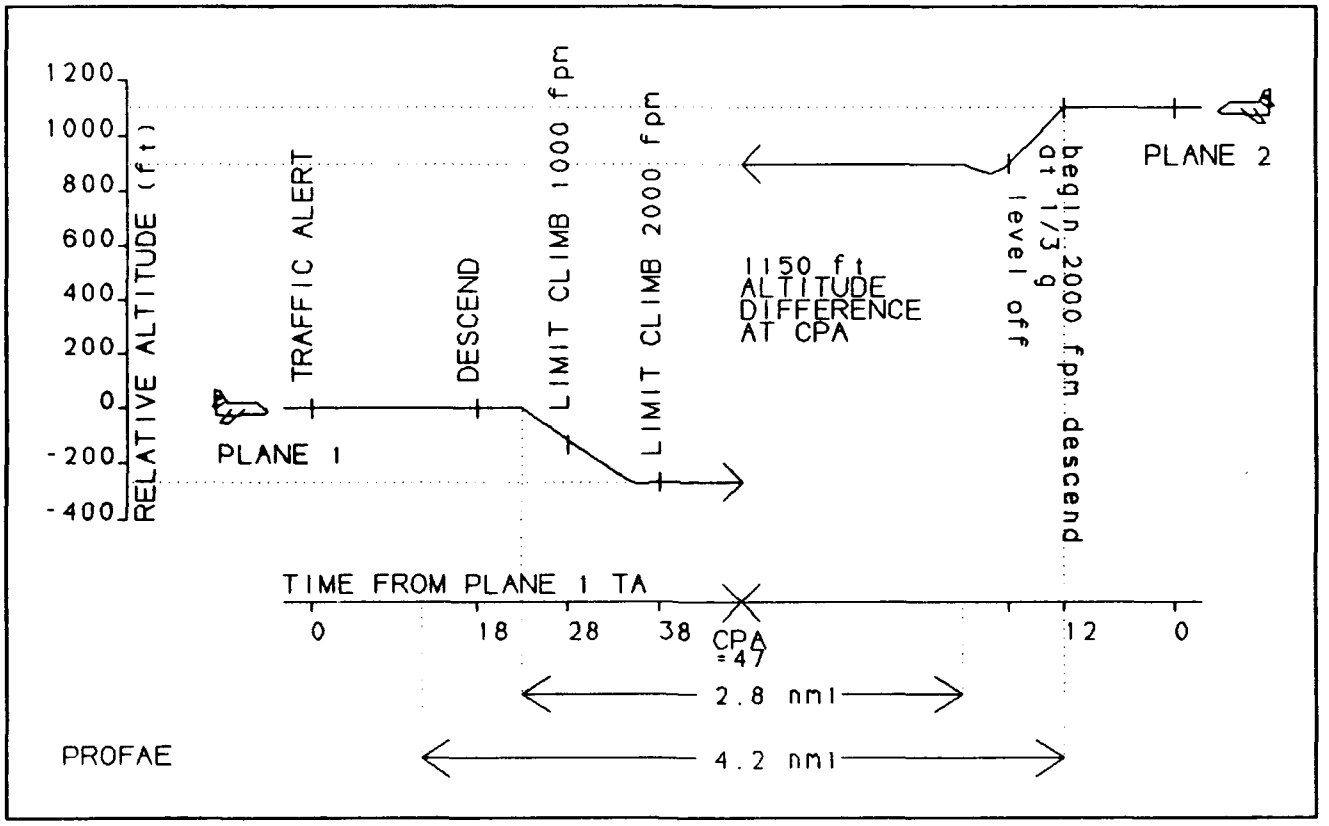
- Encounter closing speed is 50 kts.
- Encounter starting separation is 3 nmi.
- All altitudes are above 10,000 ft.

RUN 13

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *900 FT RULE*.

This encounter is a head-on. PLANE 2 will begin a 2000 fpm descent at 1/3 g 12 seconds after the PLANE 1 TCAS issues a **TRAFFIC ALERT**. PLANE 2 will continue its descent until it comes within 900 ft of the base altitude, and then level off. The PLANE 1 TCAS will defer issuing an advisory until PLANE 2 violates the 900-ft threshold, and then issue a **DESCEND** advisory. The pilot will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

- Encounter closing speed is 440 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

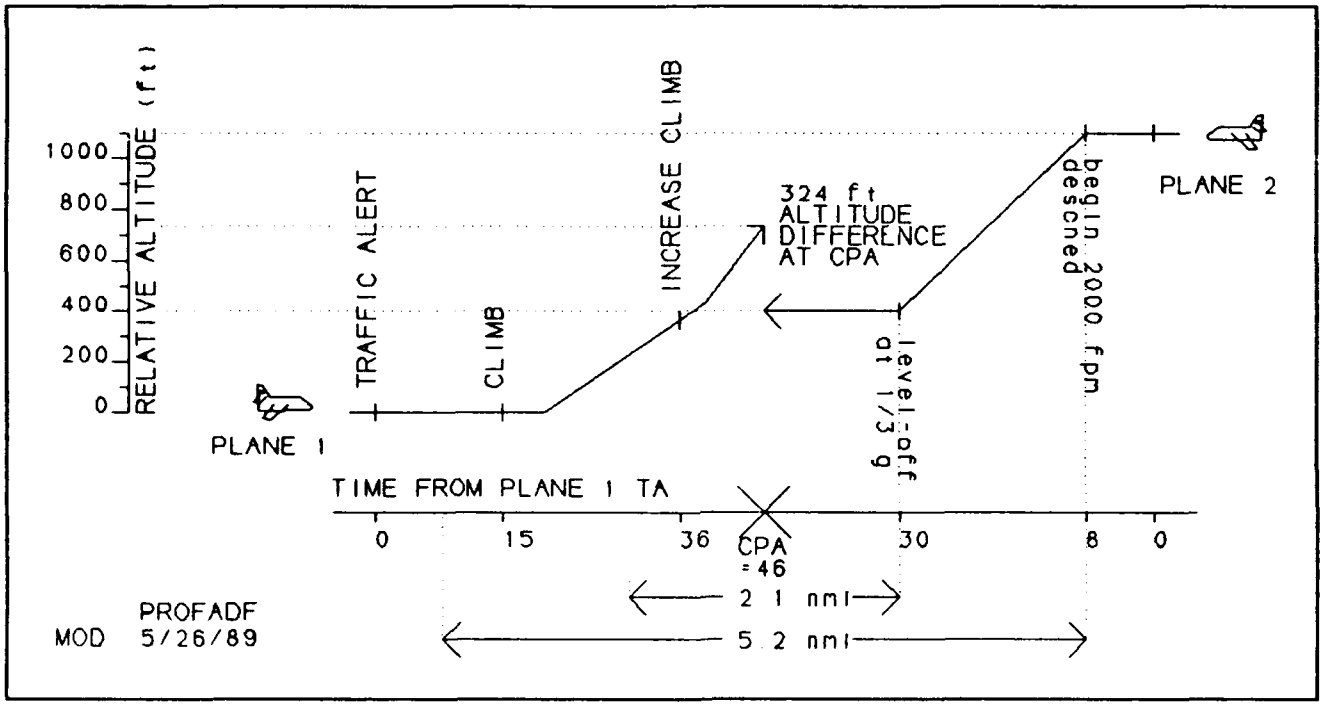
NOTE: The logic has been altered since the flight tests were performed. This encounter will not produce these results with the newer logic. An updated encounter is included in appendix B.

RUN 14

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *INSUFFICIENT TIME TO EXECUTE A REVERSAL* logic.

This encounter is a head-on. PLANE 2 descends towards PLANE 1 such that TCAS issues a **(CROSSING) CLIMB** advisory. PLANE 2 will level off at 1/3 g shortly after the advisory is issued. By the time TCAS senses the level off, there will be insufficient time to execute a reversal, and an **INCREASE CLIMB** advisory will be issued. The pilot will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

- Encounter closing speed is 500 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

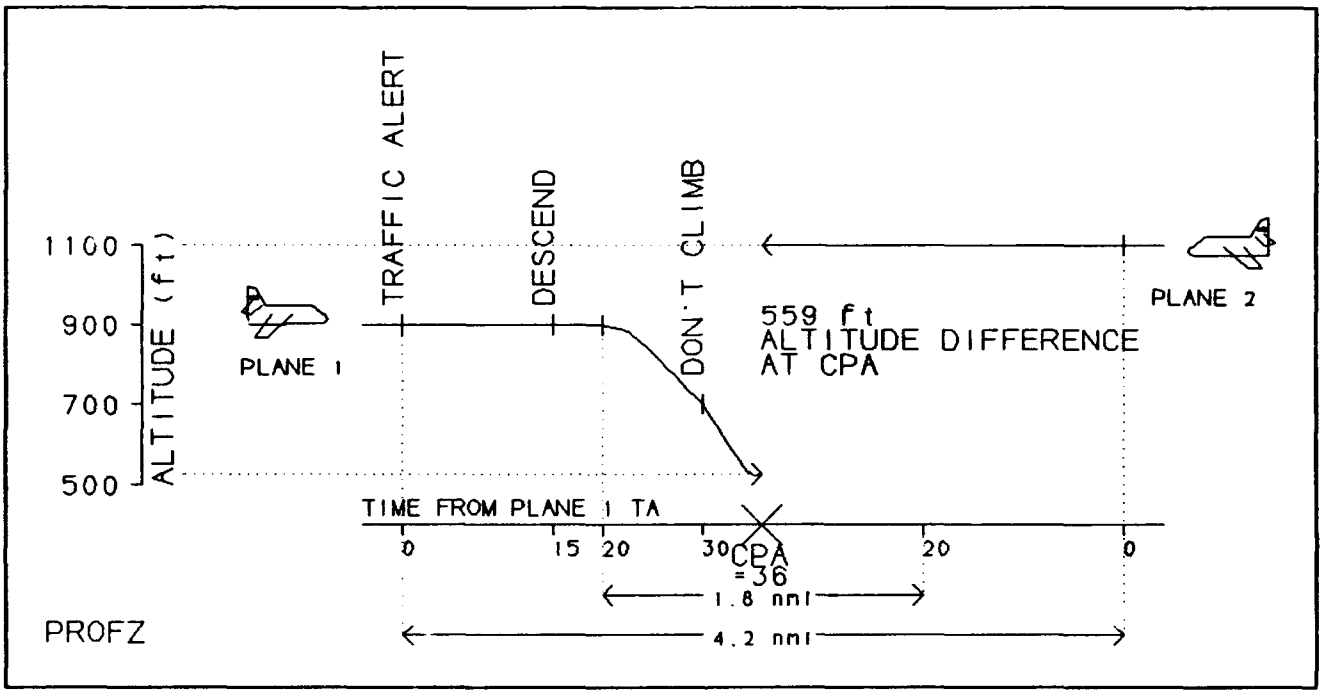
NOTE: The logic has been altered since the flight tests were performed. This encounter will not produce these results with the newer logic. An updated encounter is included in appendix B.

RUN 15

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *DESCEND INHIBIT BELOW 700 FT* rule.

This encounter is a simple head-on. The PLANE 1 TCAS will issue a **DESCEND** advisory on the approaching PLANE 2. As PLANE 1 descends through 700 ft in altitude, the advisory will weaken to a **DON'T CLIMB**. The pilot will follow all advisories.



ADDITIONAL FLIGHT INFORMATION:

- This run is altitude critical, and must be flown at the posted altitudes.
- Encounter closing speed is 430 kts.
- Encounter starting separation is 20 nmi.

NOTE: The logic has been altered since the flight tests were performed. This encounter will not produce these results with the newer logic. An updated encounter is included in appendix B.

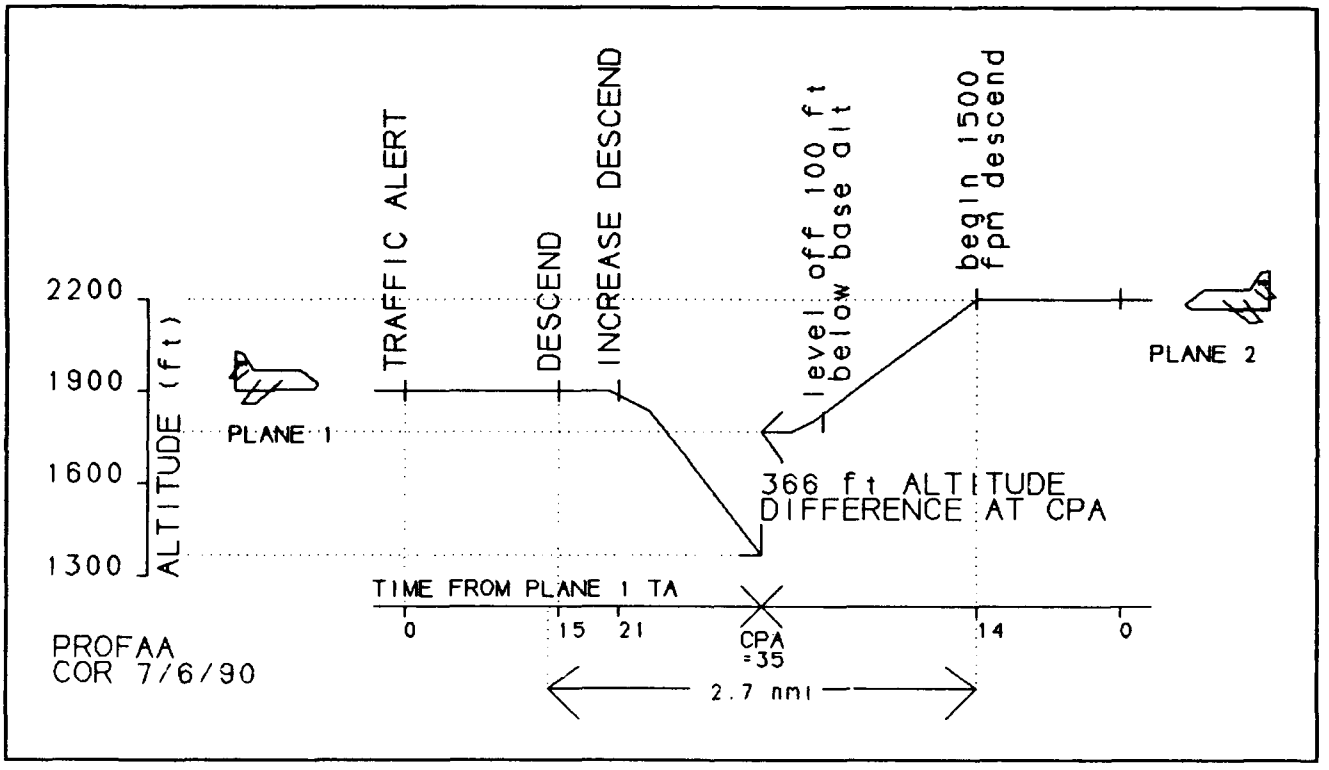
RUN 16

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *INCREASE DESCEND INHIBIT* logic.

This encounter is a head-on, with PLANE 2 beginning a 1500 fpm descent just before the PLANE 1 TCAS issues a **DESCEND** advisory. When the TCAS senses the PLANE 2 maneuver, it issues an **INCREASE DESCEND** advisory. The pilot will follow all advisories.

The next run (run 17) is identical to this run, except that the run starts at a lower altitude. This lower altitude causes the INCREASE DESCEND advisory to be suppressed.



ADDITIONAL FLIGHT INFORMATION:

- This run is altitude critical, and must be flown at the posted altitudes.
- Encounter closing speed is 470 kts.
- Encounter starting separation is 20 nmi.
- The **INCREASE DESCEND** lessens to a **DESCEND** at CPA.

NOTE: While this encounter will produce these results with the final Change 6 logic, an updated encounter is included in appendix B which also demonstrates the DESCEND INHIBIT logic.

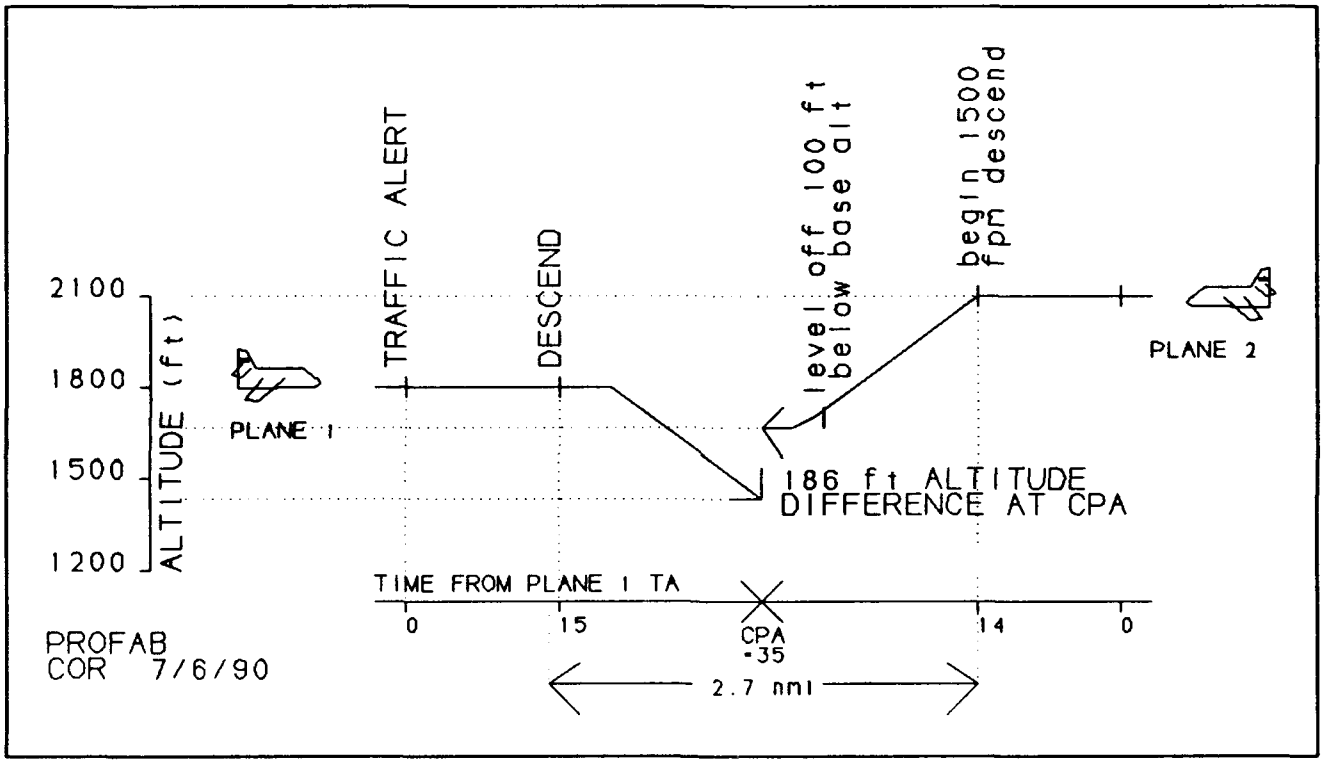
RUN 17

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *INCREASE DESCEND INHIBIT* logic.

This encounter is a head-on, with PLANE 2 beginning a 1500 fpm descent just before the PLANE 1 TCAS issues a **DESCEND** advisory. When the TCAS senses the PLANE 2 maneuver, it considers issuing an **INCREASE DESCEND** advisory, but suppresses it due to the low altitude. The pilot will follow all advisories.

The previous run (run 16) is identical to this run, except that the run starts at a higher altitude. This higher altitude allows the INCREASE DESCEND advisory to be issued.



ADDITIONAL FLIGHT INFORMATION:

- This run is altitude critical, and must be flown at the posted altitudes.
- Encounter closing speed is 470 kts.
- Encounter starting separation is 20 nmi.

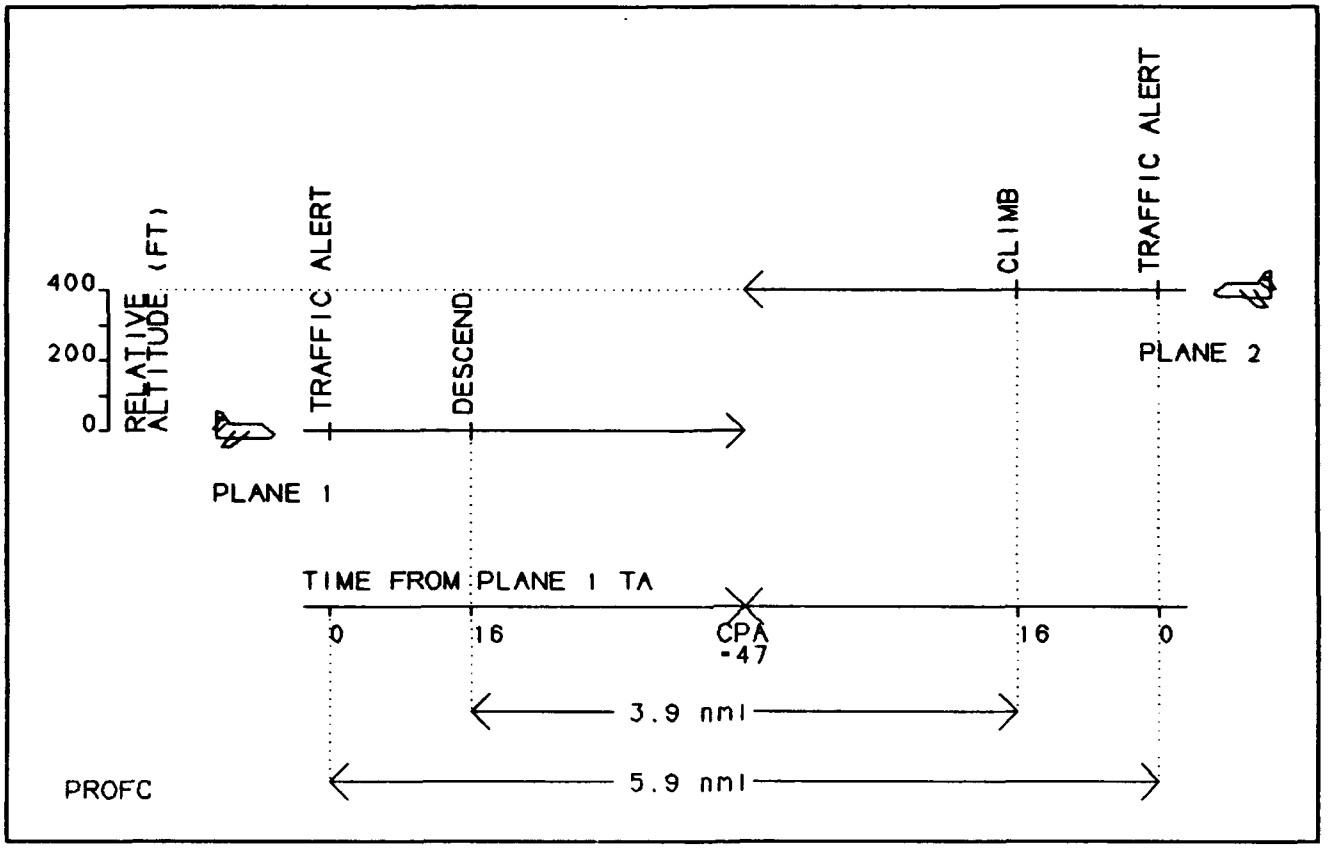
NOTE: The logic has been altered since the flight tests were performed. This encounter will not produce these results with the newer logic. An updated encounter is included in appendix B.

RUN 18

PLANE 1: TCAS HIGH ID PLANE 2: TCAS LOW ID

This run is a basic system test run.

The run is a simple TCAS to TCAS head-on. Neither pilot will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

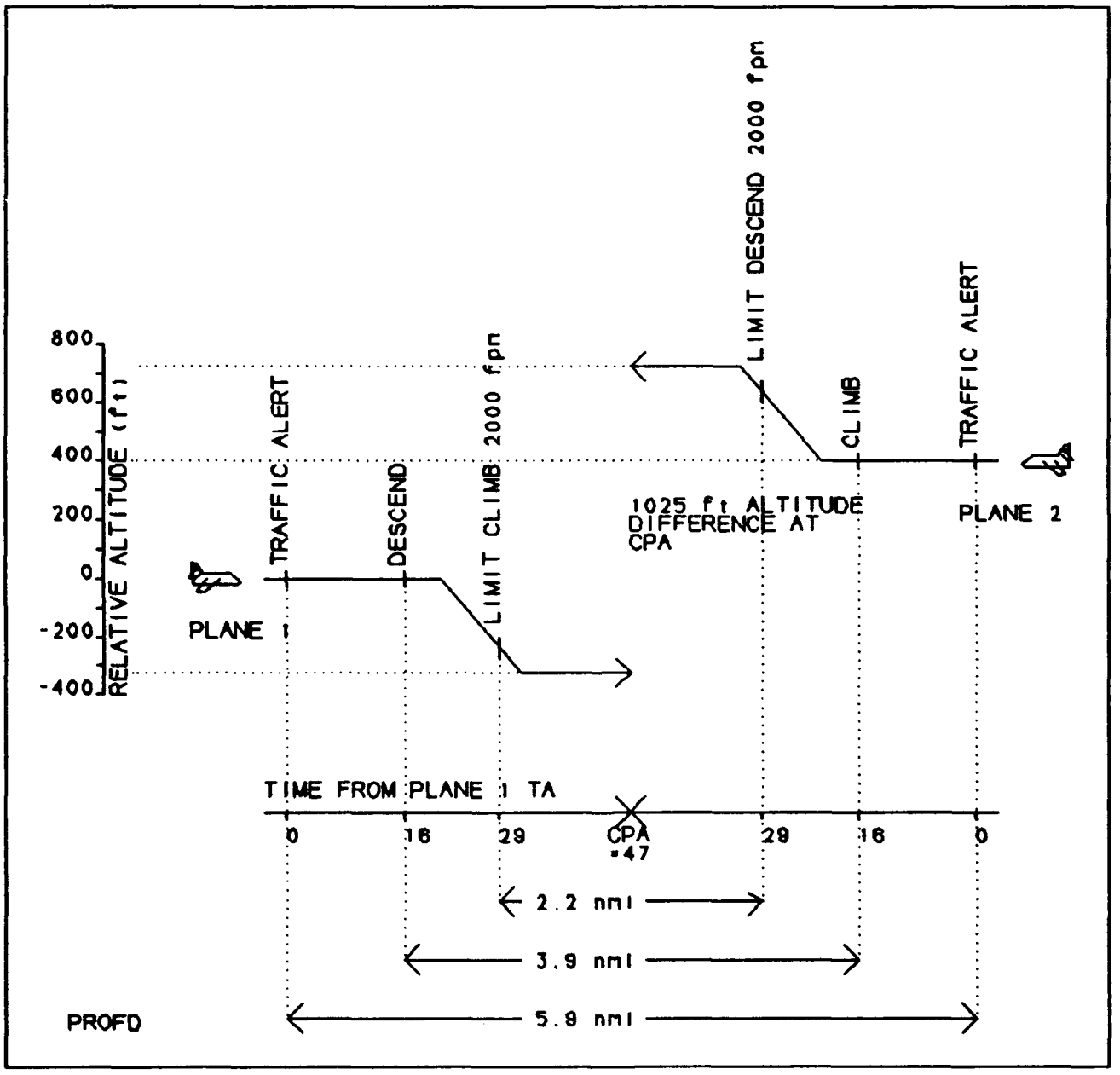
- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 19

PLANE 1: TCAS HIGH ID PLANE 2: TCAS LOW ID

This run is a basic system test run.

The run is a simple TCAS to TCAS head-on. Both pilots will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

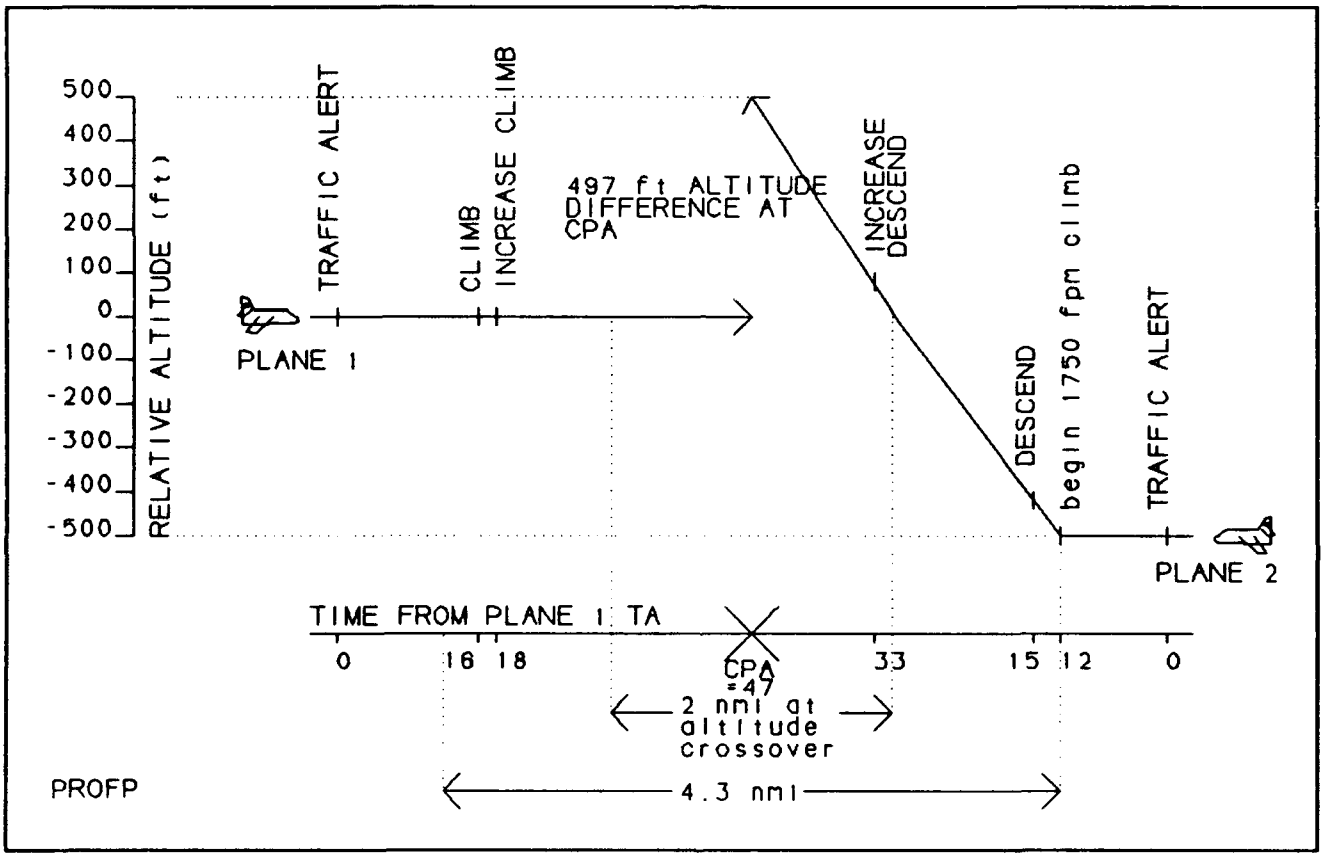
- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 20

PLANE 1: TCAS HIGH ID PLANE 2: TCAS LOW ID

This run designed to test the *INCREASE ADVISORY and COORDINATION* logic.

The run is a TCAS to TCAS head-on. PLANE 2 will begin a climb towards PLANE 1, which will cause the PLANE 1 TCAS to issue a **CLIMB** advisory, and the PLANE 2 TCAS to issue a **DESCEND**. The PLANE 1 TCAS will then issues an **INCREASE CLIMB** advisory. Both pilots will ignore the advisories, which will cause the PLANE 2 TCAS to issue and **INCREASE DESCEND** advisory. All advisories are to be ignored.



ADDITIONAL FLIGHT INFORMATION:

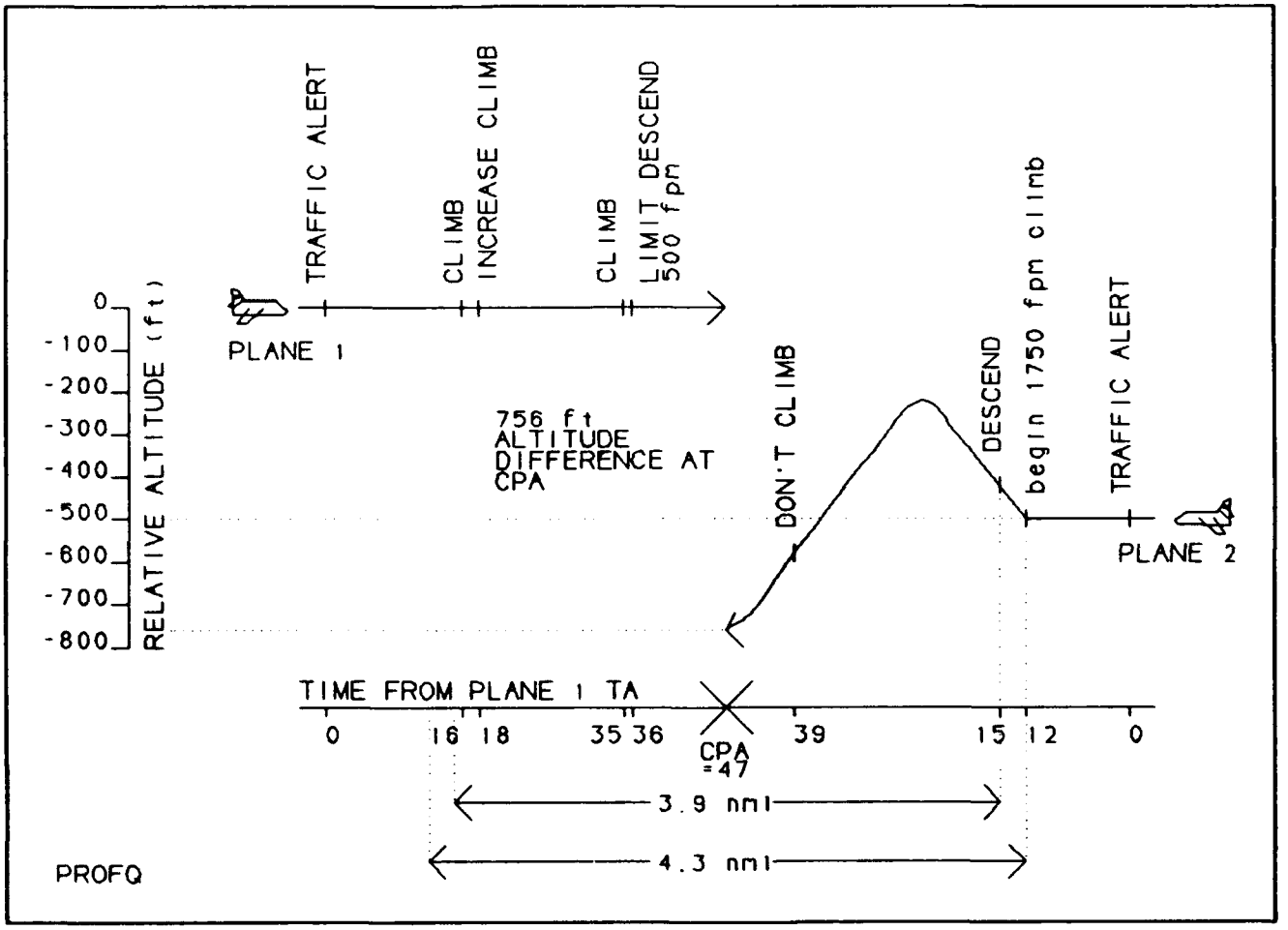
- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 21

PLANE 1: TCAS HIGH ID PLANE 2: TCAS LOW ID

This run designed to test the *INCREASE ADVISORY and COORDINATION* logic.

The run is a TCAS to TCAS head-on. PLANE 2 will begin a climb towards PLANE 1, which will cause the PLANE 1 TCAS to issue a **CLIMB** advisory, and the PLANE 2 TCAS to issue a **DESCEND**. The PLANE 1 TCAS will then issues an **INCREASE CLIMB** advisory. The PLANE 2 pilot will follow the advisories, but the PLANE 1 pilot will ignore the advisories. When adequate separation is projected, both TCAS units will decrease advisory strength.



ADDITIONAL FLIGHT INFORMATION:

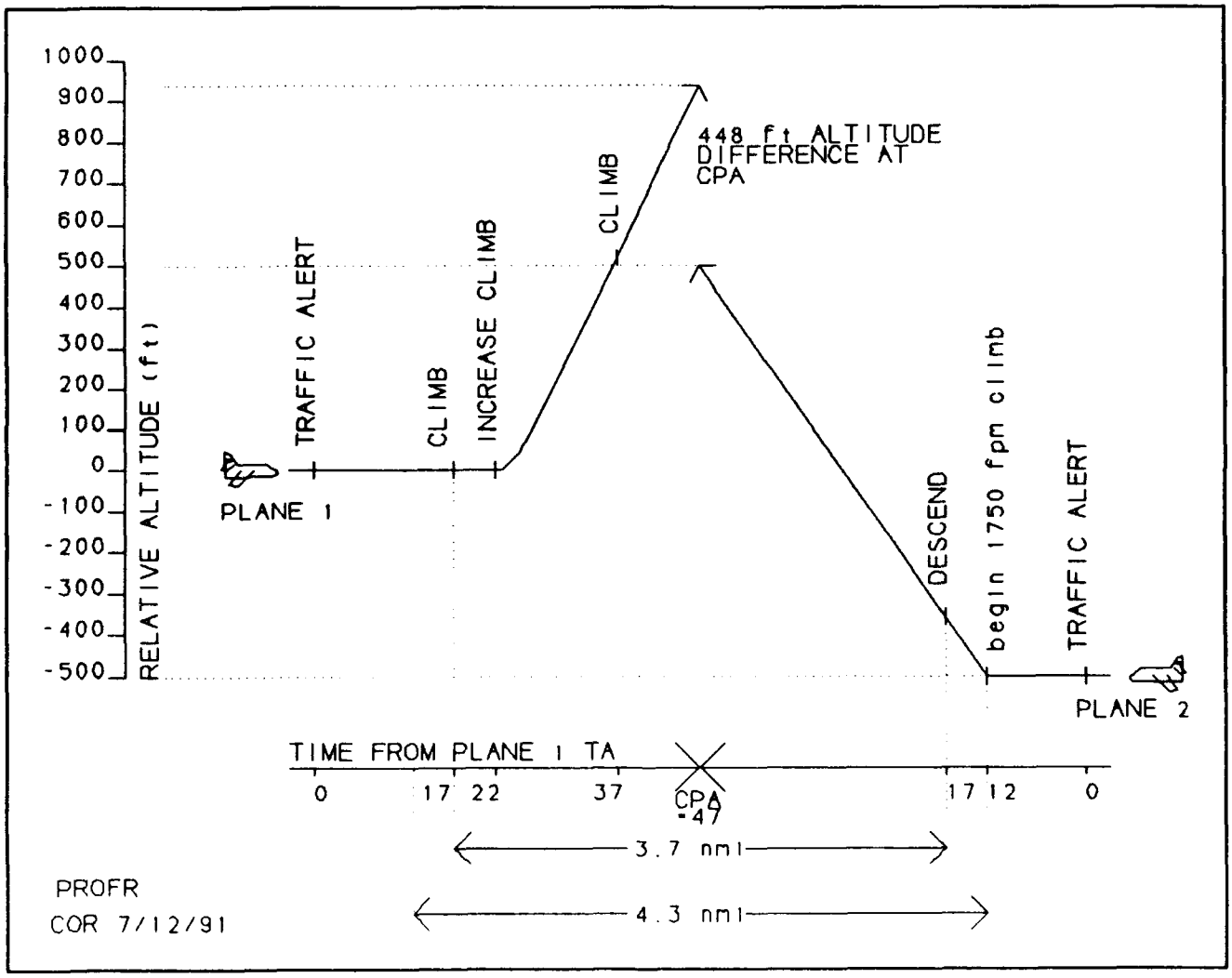
- **Encounter closing speed is 460 kts.**
- **Encounter starting separation is 20 nmi.**
- **All altitudes are above 10,000 ft.**

RUN 22

PLANE 1: TCAS LOW ID PLANE 2: TCAS HIGH ID

This run designed to test the *INCREASE ADVISORY and COORDINATION* logic.

The run is a TCAS to TCAS head-on. PLANE 2 will begin a climb towards PLANE 1, which will cause the PLANE 1 TCAS to issue a **CLIMB** advisory, and the PLANE 2 TCAS to issue a **DESCEND**. The PLANE 1 TCAS will then issues an **INCREASE CLIMB** advisory. The PLANE 1 pilot will follow the advisories, but the PLANE 2 pilot will ignore the advisories. When the PLANE 1 TCAS projects adequate separation will be achieved, the strength of the advisory will be decreased to a CLIMB.



ADDITIONAL FLIGHT INFORMATION:

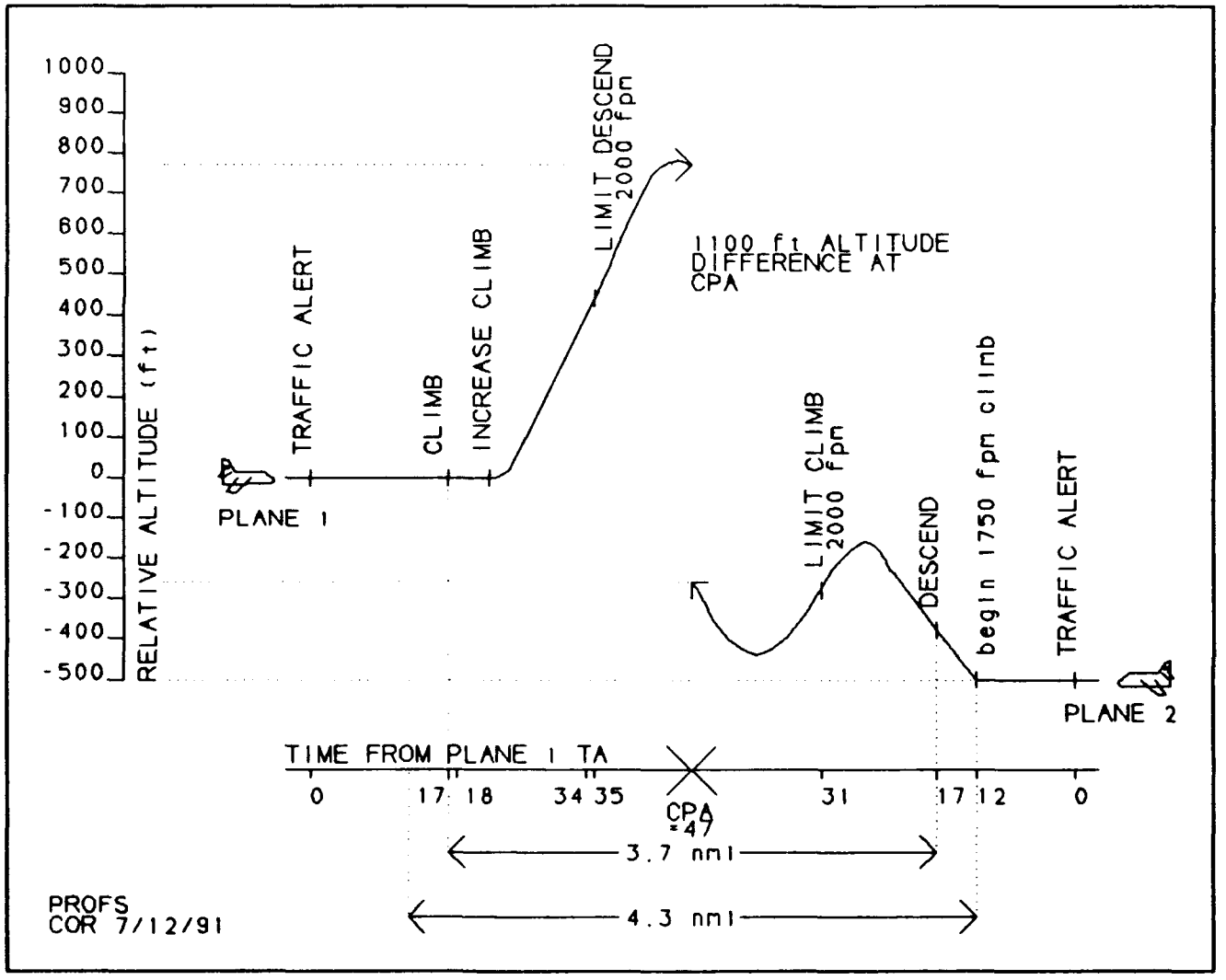
- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 23

PLANE 1: TCAS LOW ID PLANE 2: TCAS HIGH ID

This run designed to test the *INCREASE ADVISORY and COORDINATION* logic.

The run is a TCAS to TCAS head-on. PLANE 2 will begin a climb towards PLANE 1, which will cause the PLANE 1 TCAS to issue a **CLIMB** advisory, and the PLANE 2 TCAS to issue a **DESCEND**. The PLANE 1 TCAS will then issues an **INCREASE CLIMB** advisory. Both pilots will follow the advisories. When the TCAS units project adequate separation, the advisory strengths will be decreased.



ADDITIONAL FLIGHT INFORMATION:

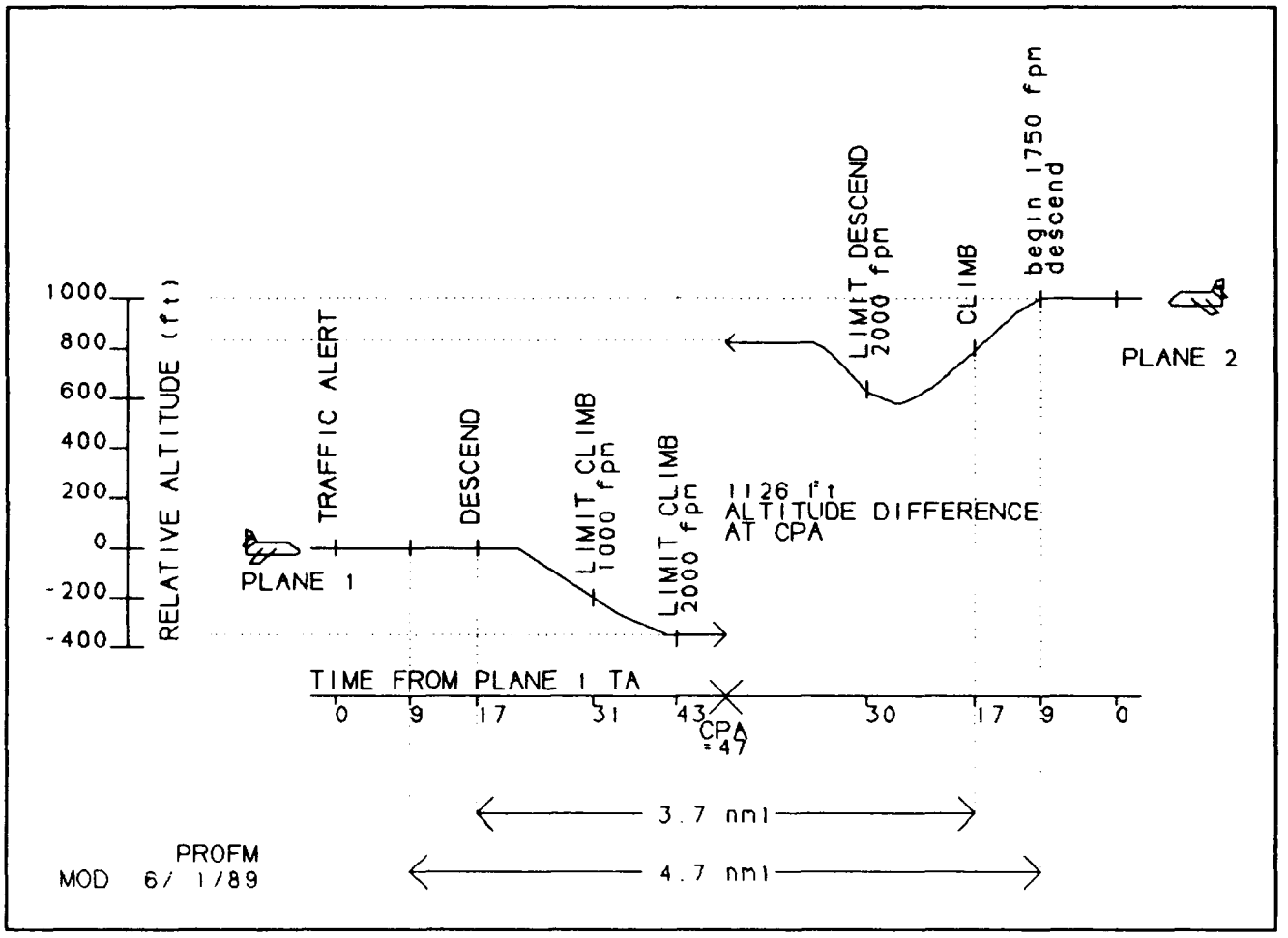
- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 24

PLANE 1: TCAS LOW ID PLANE 2: TCAS HIGH ID

This run designed to test the effect of the *LEVEL WAIT* logic on PLANE 1 (which has the low MODE S ID).

The run is a TCAS to TCAS head-on. PLANE 2 will begin a 1750 fpm descent 9 seconds after receiving a **TRAFFIC ALERT**. The PLANE 1 TCAS will defer to the maneuvering aircraft, allowing the PLANE 2 TCAS to choose a **CLIMB** advisory. The PLANE 1 TCAS should then issue a **DESCEND** advisory. Both pilots will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

NOTE: The logic has been altered since the flight tests were performed. This encounter will not produce these results with the newer logic. An updated encounter is included in appendix B.

APPENDIX B

DETAILED DESCRIPTIONS OF THE ENCOUNTERS REVISED FOR THE FINAL CHANGE 6 LOGIC (SEPTEMBER 1989)

OVERVIEW

The validation flight testing of the Change 6 logic was conducted prior to acceptance of the logic for the Minimum Operational Performance Standards (MOPS). Several changes were made to the logic standard after it had been implemented in the Limited Installation Program (LIP) units for the flight tests. As a result of these changes, some of the original encounters will not stress the desired area in the final version of the Change 6 logic, while others will not produce the expected results. This appendix contains new encounters which will stress the desired areas in the newer logic and produce the expected results. These encounters may be substituted for their numerical counterparts in the original (as flight tested) encounter set for use with the accepted Change 6 logic standard.

SUMMARY OF CHANGES

Runs 3 & 4: These runs are designed to test the resolution advisory (RA) Reversal Due to Intruder Level-off logic. The change of the 900 ft rule to the 600 ft rule delayed the issuance of the advisory such that no RA reversal was generated. The initial altitude separation has been decreased so that the reversal will be issued.

Run 13: This run was designed to test the 900 ft rule. The current logic replaces the 900 ft rule with the 600 ft rule, so the run has been revised to test the 600 ft rule.

Run 14: This run is designed to test the Insufficient Time to Execute a Reversal logic. The change of the 900 ft rule to the 600 ft rule impacted the encounter geometry enough to allow an RA Reversal to be issued. The initial altitude separation has been decreased so that the reversal will not be issued.

Run 15: This run is designed to test the Low Altitude Descend Inhibit rule. The descend inhibit altitude was raised from 700 to 1000 ft in the final logic, so the base altitude has been increased by 300 ft.

Runs 16 & 17: These runs are designed to test the Increase Descend Inhibit logic. The increase descend inhibit altitude was lowered from 1800 ft to 1450 ft in the final logic, so the base altitudes of these encounters were lowered as well.

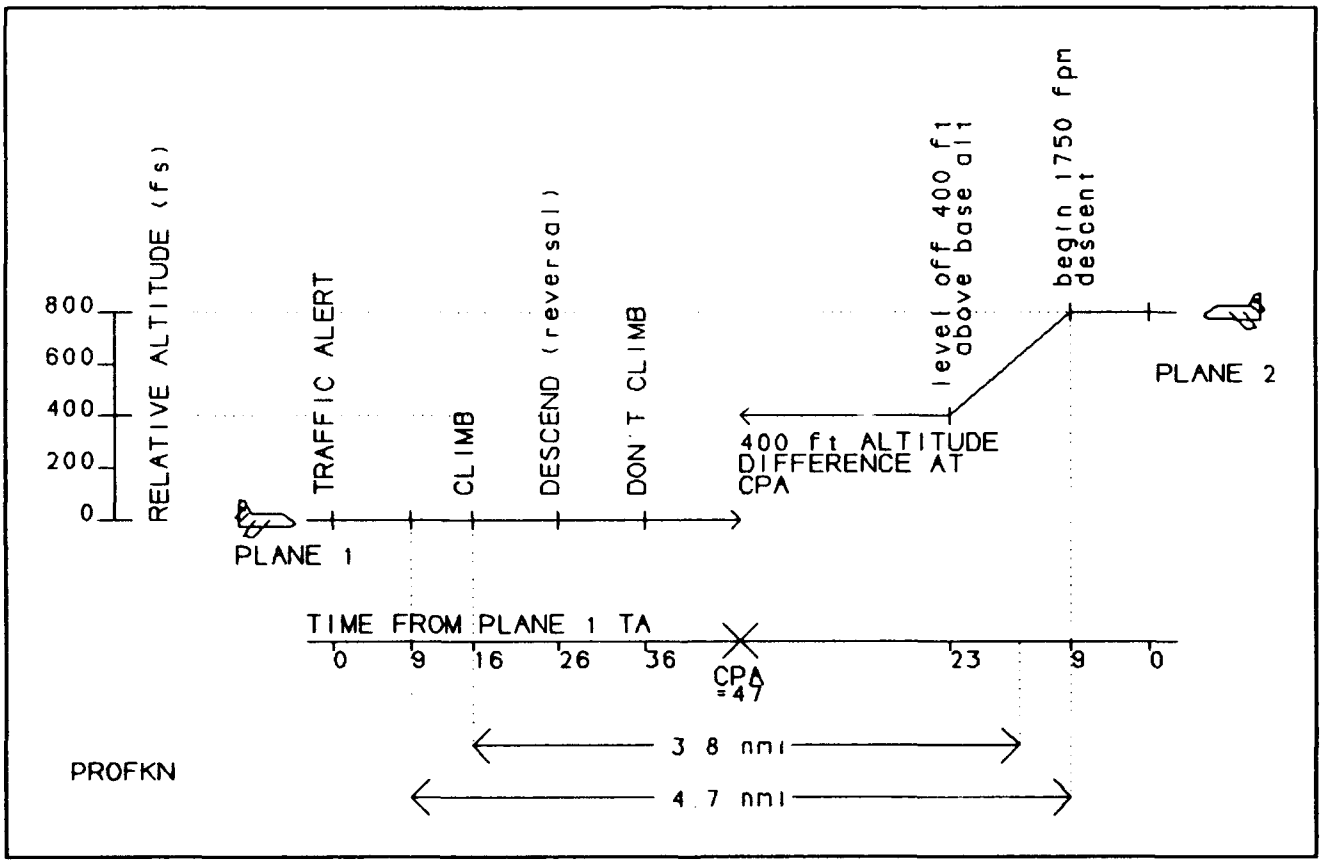
Run 24: This run is designed to test the Level Wait logic. The change of the 900 ft rule to the 600 ft rule required that the initial altitude separations be reduced to allow this logic to be tested.

RUN 3 REVISED 6/28/90 FOR CURRENT CHANGE 6 LOGIC

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *RA REVERSAL DUE TO INTRUDER LEVEL-OFF* logic.

In this encounter PLANE 2 will start a 1750 fpm descent 9 seconds after PLANE 1 receives a **TRAFFIC ALERT**. PLANE 2 will then level off 400 ft above the base altitude. TCAS will issue a **CLIMB** advisory on the descending PLANE 2, followed by a **DESCEND REVERSAL** when the level-off is detected. The TCAS pilot will ignore the advisories.



ADDITIONAL FLIGHT INFORMATION:

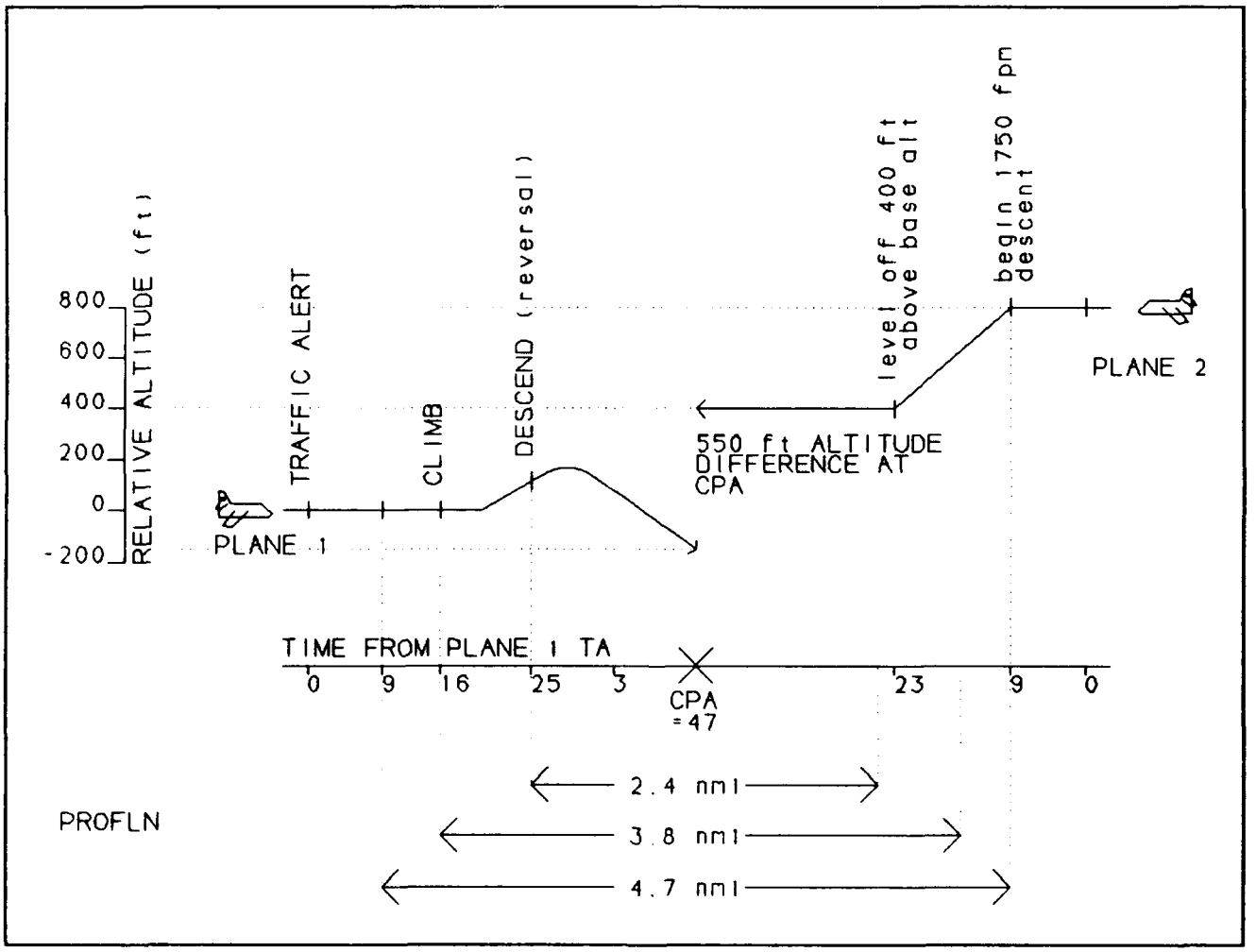
- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 4 REVISED 6/28/90 FOR CURRENT CHANGE 6 LOGIC

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *RA REVERSAL DUE TO INTRUDER LEVEL-OFF* logic.

In this encounter PLANE 2 will start a 1750 fpm descent 9 seconds after PLANE 1 receives a **TRAFFIC ALERT**. PLANE 2 will then level off 400 ft above the base altitude. TCAS will issue a **CLIMB** advisory on the descending PLANE 2, followed by a **DESCEND REVERSAL** when the level-off is detected. The TCAS pilot will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

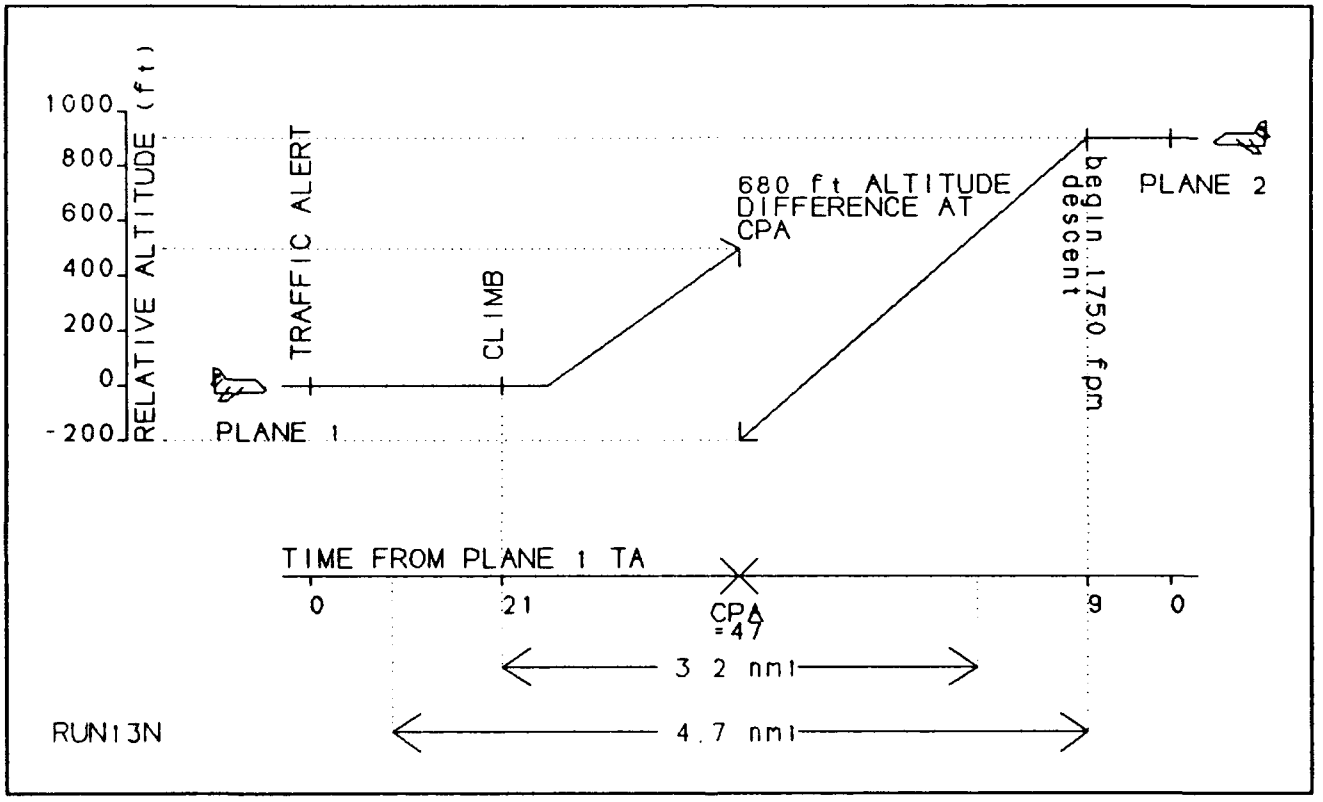
- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 13 REVISED 6/28/90 FOR CURRENT CHANGE 6 LOGIC

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *600 FT RULE*.

This encounter is a head-on. PLANE 2 will begin a 1750 fpm descent 9 seconds after the PLANE 1 TCAS issues a **TRAFFIC ALERT**. The PLANE 1 TCAS will defer issuing an advisory until PLANE 2 violates the 600 ft threshold, and then issue a **CLIMB** advisory. The pilot will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

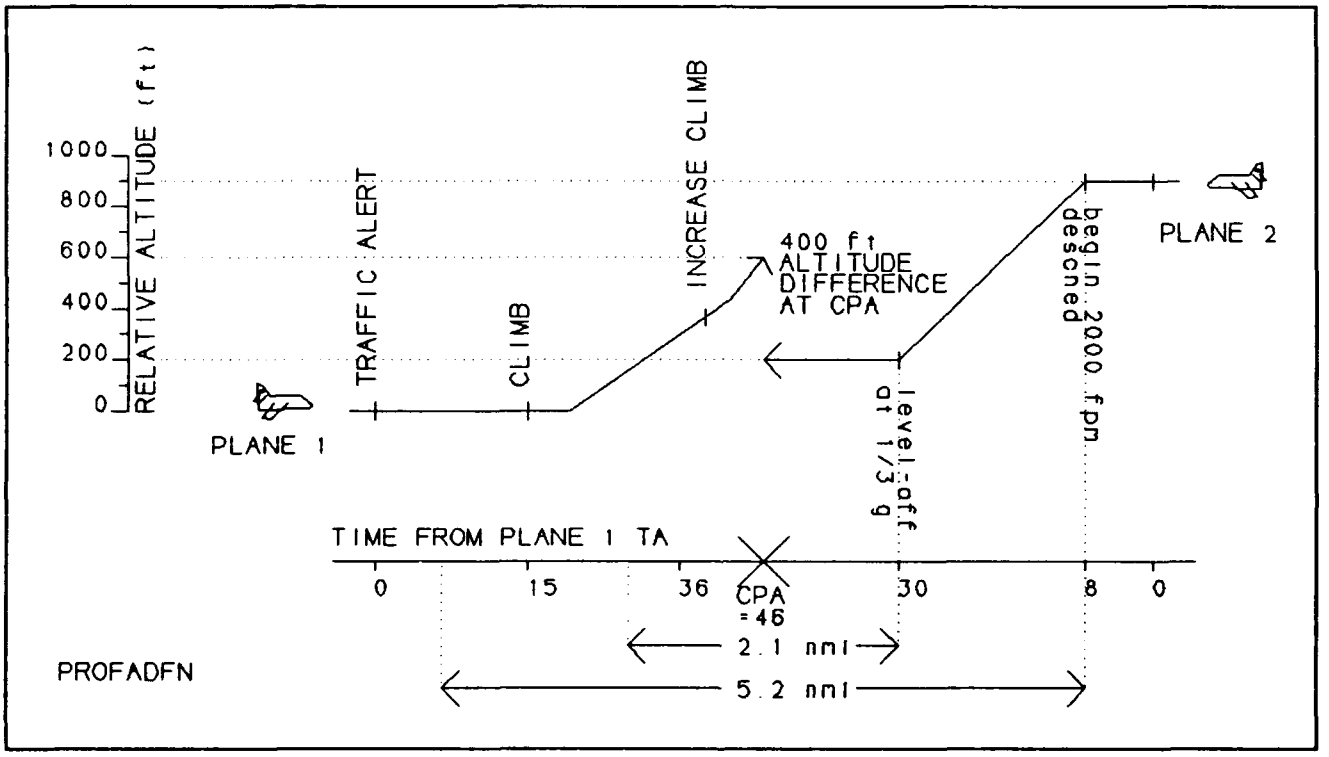
- Encounter closing speed is 440 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 14 REVISED 6/28/90 FOR CURRENT CHANGE 6 LOGIC

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *INSUFFICIENT TIME TO EXECUTE A REVERSAL* logic.

This encounter is a head-on. PLANE 2 descends towards PLANE 1 such that TCAS issues a **(CROSSING) CLIMB** advisory. PLANE 2 will level off at 1/3 g shortly after the advisory is issued. By the time TCAS senses the level off, there will be insufficient time to execute a reversal, and an **INCREASE CLIMB** advisory will be issued. The pilot will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

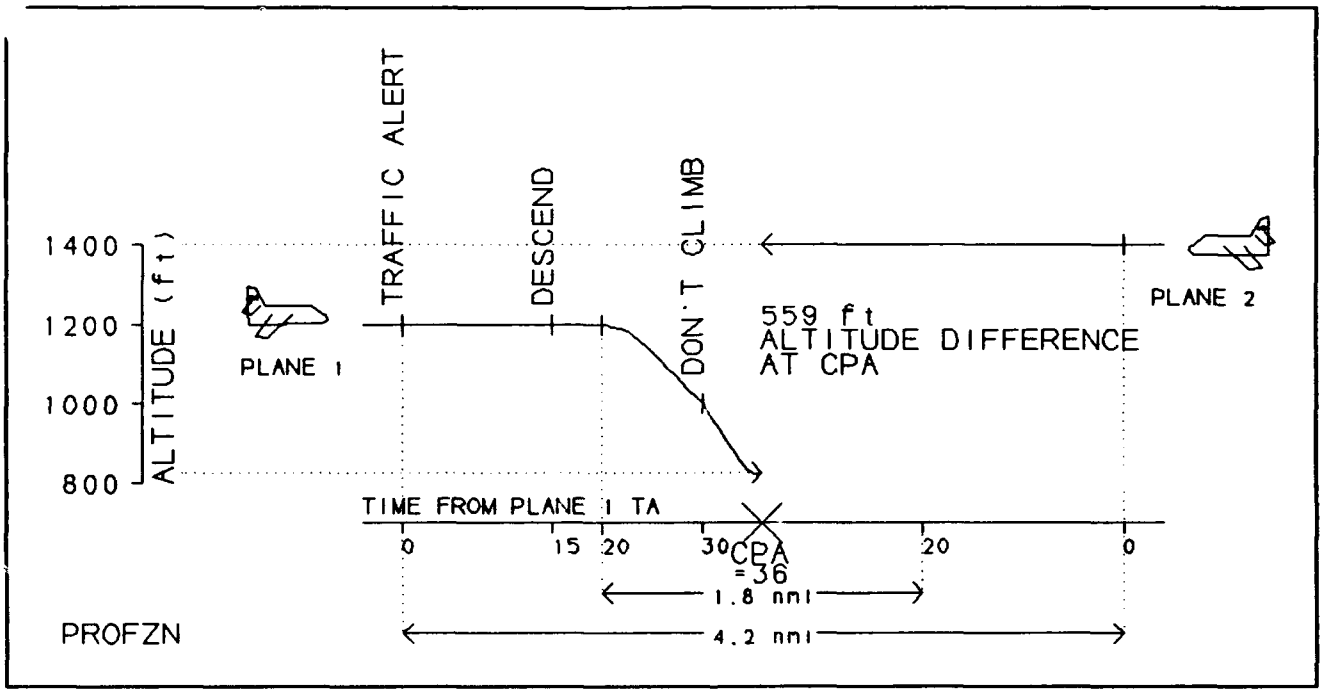
- Encounter closing speed is 500 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

RUN 15 REVISED 4/11/91 FOR FINAL CHANGE 6 LOGIC

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *DESCEND INHIBIT BELOW 1000 FT* rule.

This encounter is a simple head-on. The PLANE 1 TCAS will issue a **DESCEND** advisory on the approaching PLANE 2. As PLANE 1 descends through 1000 ft in altitude, the advisory will weaken to a **DON'T CLIMB**. The pilot will follow all advisories.



ADDITIONAL FLIGHT INFORMATION:

- This run is altitude critical, and must be flown at the posted altitudes.
- Encounter closing speed is 430 kts.
- Encounter starting separation is 20 nmi.

RUN 16 REVISED 4/30/91 FOR FINAL CHANGE 6 LOGIC

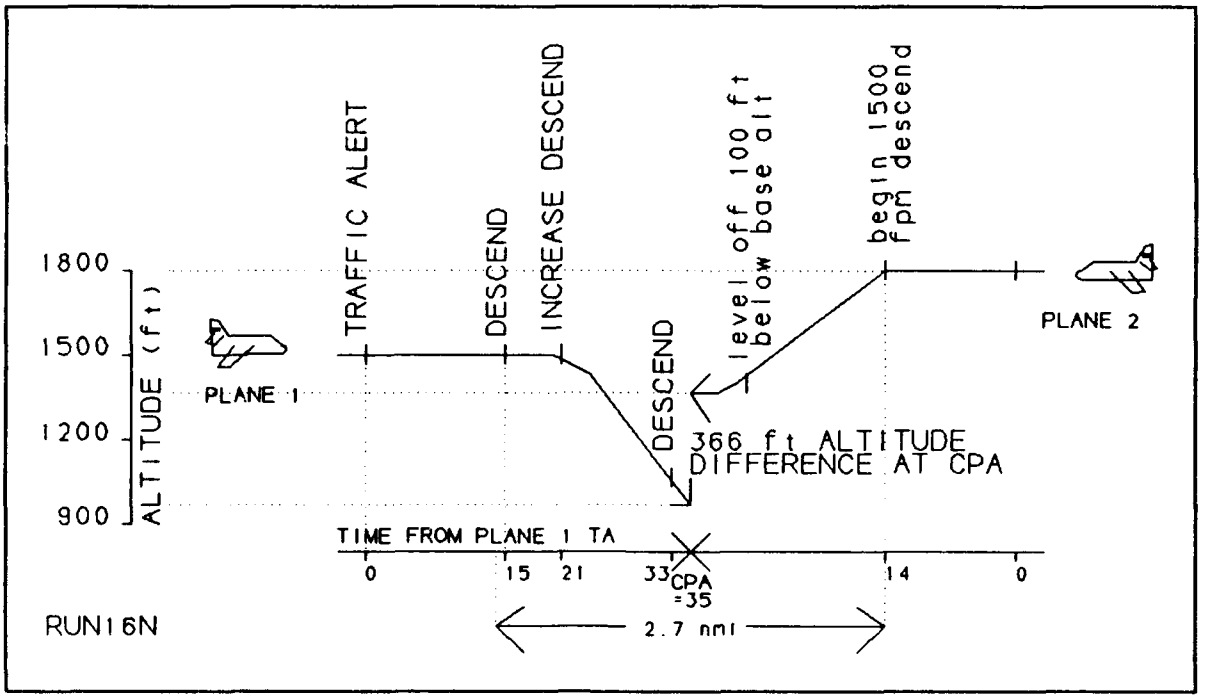
PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *INCREASE DESCEND INHIBIT* logic.

This encounter is a head-on, with PLANE 2 beginning a 1500 fpm descent just before the PLANE 1 TCAS issues a **DESCEND** advisory. When the TCAS senses the PLANE 2 maneuver, it issues an **INCREASE DESCEND** advisory. Ten seconds after PLANE 1 passes through the Increase Descend Inhibit altitude (1450 ft), the advisory will be softened to a **DESCEND** by the Increase Descend Inhibit logic. The pilot will follow all advisories.

NOTE: TCAS will continue the DESCEND advisory until the CLEAR OF CONFLICT is issued 4 seconds after CPA, at which time the aircraft altitude will be 800 ft. By the time the plane levels off, it will reach an altitude of 500 ft. TCAS should weaken the advisory to a DON'T CLIMB prior to CPA to prevent the airplane from reaching such a low altitude. This logic error has been reported to The MITRE Corporation.

The next run (run 17) is identical to this run, except that the run starts at a lower altitude. This lower altitude causes the INCREASE DESCEND advisory to be suppressed.



ADDITIONAL FLIGHT INFORMATION:

- This run is altitude critical, and must be flown at the posted altitudes.
- Encounter closing speed is 470 kts.
- Encounter starting separation is 20 nmi.

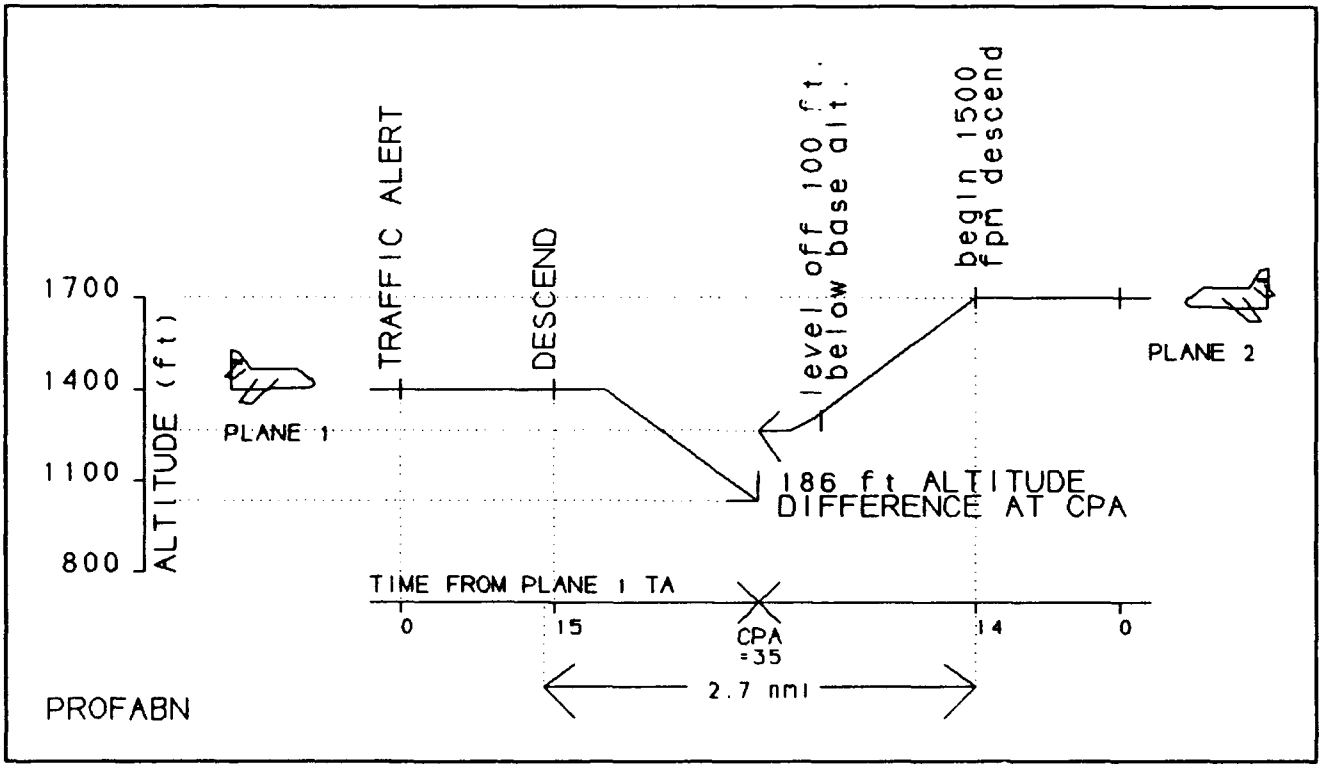
RUN 17 REVISED 6/28/90 FOR CURRENT CHANGE 6 LOGIC

PLANE 1: TCAS PLANE 2: MODE C

This run is designed to test the *INCREASE DESCEND INHIBIT* logic.

This encounter is a head-on, with PLANE 2 beginning a 1500 fpm descent just before the PLANE 1 TCAS issues a **DESCEND** advisory. When the TCAS senses the PLANE 2 maneuver, it considers issuing an **INCREASE DESCEND** advisory, but suppresses it due to the low altitude. The pilot will follow all advisories.

The previous run (run 16) is identical to this run, except that the run starts at a higher altitude. This higher altitude allows the INCREASE DESCEND advisory to be issued.



ADDITIONAL FLIGHT INFORMATION:

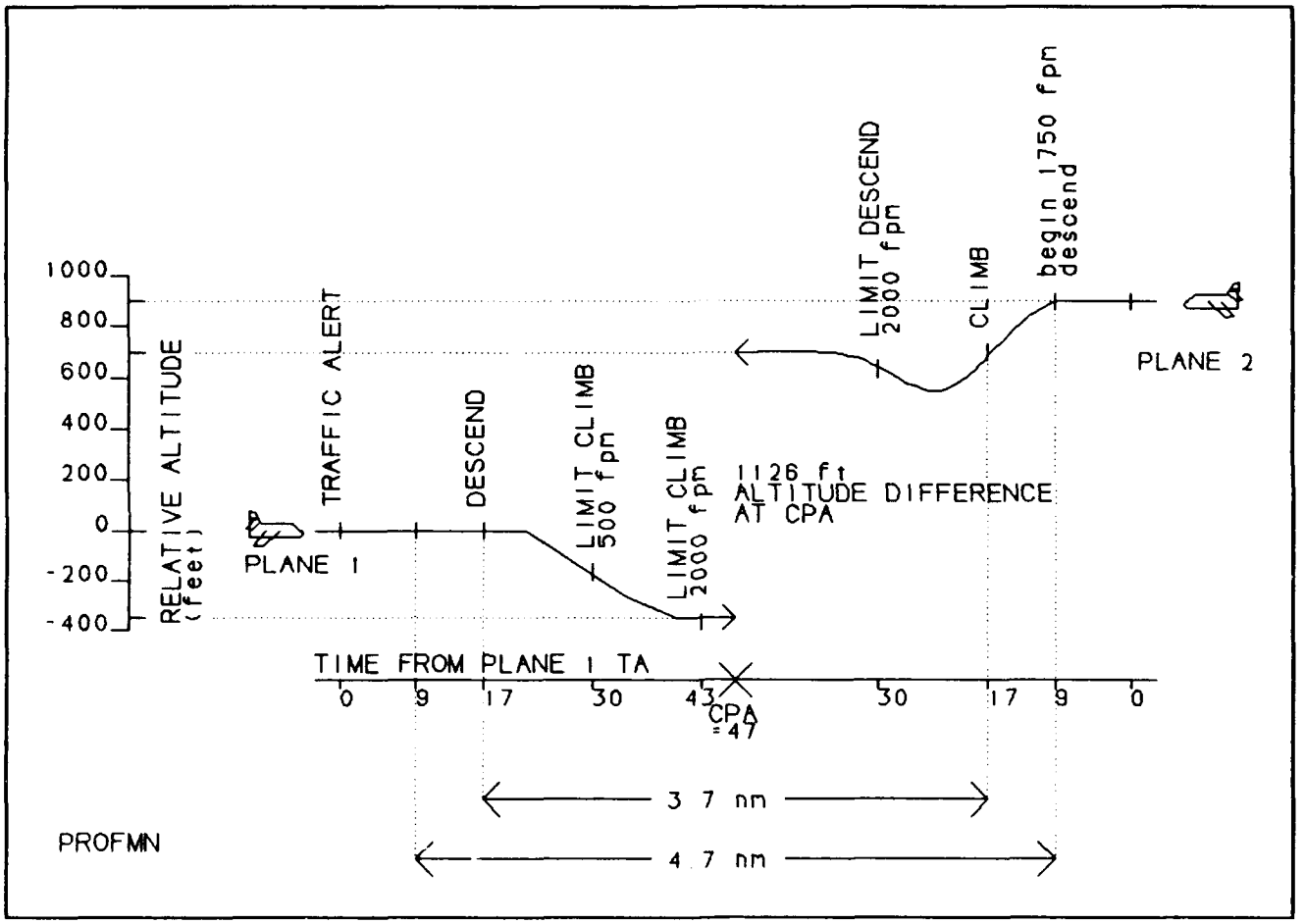
- This run is altitude critical, and must be flown at the posted altitudes.
- Encounter closing speed is 470 kts.
- Encounter starting separation is 20 nmi.

RUN 24 REVISED 6/28/90 FOR CURRENT CHANGE 6 LOGIC

PLANE 1: TCAS LOW ID PLANE 2: TCAS HIGH ID

This run designed to test the effect of the *LEVEL WAIT* logic on PLANE 1 (which has the low MODE S ID).

The run is a TCAS to TCAS head-on. PLANE 2 will begin a 1750 fpm descent 9 seconds after receiving a **TRAFFIC ALERT**. The PLANE 1 TCAS will defer to the maneuvering aircraft, allowing the PLANE 2 TCAS to choose a **CLIMB** advisory. The PLANE 1 TCAS should then issue a **DESCEND** advisory. Both pilots will follow the advisories.



ADDITIONAL FLIGHT INFORMATION:

- Encounter closing speed is 460 kts.
- Encounter starting separation is 20 nmi.
- All altitudes are above 10,000 ft.

APPENDIX C

DETAILED DESCRIPTIONS OF THE ENCOUNTERS OF INTEREST

LOGIC PERFORMANCE QUESTIONS

Two encounters generated significant concern about the performance of the Traffic Alert and Collision Avoidance System (TCAS) logic. Analysis of the data revealed, however, that in both cases the TCAS logic worked correctly and as designed. Sluggish pilot response to the advisories limited the effectiveness of the advisories. The TCAS performance is detailed below.

Note: All flight data plots include the TCAS logic advisories unless otherwise noted. The aural advisories issued by the TCAS system may differ significantly from the TCAS logic advisories depending on own-aircraft maneuvering and pilot performance. Aural advisory data was not recorded on the Bendix Limited Installation Program (LIP) system.

RUN 17 OF APRIL 17, 1989

ENCOUNTER DESCRIPTION.

Encounter 17 is designed to test the INCREASE DESCEND INHIBIT logic by inducing a situation that would normally result in an INCREASE DESCEND advisory. However, the encounter is performed at a sufficiently low altitude that the INCREASE DESCEND is suppressed, and only a DESCEND advisory is issued. The full encounter description is included in appendix A.

During this particular execution of the encounter, a DESCEND to CLIMB REVERSAL was issued. The pilot of the TCAS plane believed that this CLIMB REVERSAL was issued while the target plane was above the TCAS airplane. All viewing the encounter agreed that the vertical miss distance was considerably less than expected. Figure C-1 is a plot of the flight data.

ENCOUNTER ANALYSIS.

This execution of the run held little similarity to the planned encounter. The initial altitude separation was only 200 feet (ft), 100 ft less than planned. The intruder executed the descend maneuver at the correct time, but at 2500 feet per minute (fpm) instead of 1500 fpm. The intruder leveled off 100 ft below the expected altitude. The combination of the lower starting altitude separation, the greater descent rate, and the lower level-off altitude created an altitude crossing situation. The TCAS reacted to this geometry by issuing a CLIMB REVERSAL. The intruder aircraft was more than 100 ft below the TCAS aircraft and still descending when this advisory was issued.

The pilot responded to the DESCEND advisory as expected, except that the 1500 fpm rate was not achieved until the CLIMB REVERSAL was posted for 3 seconds (s), or 11s from the initial DESCEND resolution advisory (RA). (The expected time to reach the desired descend rate is 7.5s.) The descent rate continued to increase until it peaked at over 2000 fpm. The descent was arrested 7 sec after the CLIMB REVERSAL was posted, during which time the TCAS aircraft had descended an additional 200 ft and the intruder aircraft had leveled off. This

created a second altitude crossing at only 7s before the closest point of approach (CPA). The TCAS pilot continued the reversal, and achieved the expected climb rate only at CPA. The expected time for a complete reversal includes 2.5s for pilot reaction, 2.5s to stop the descent, 2.5s to reach the climb rate, and 2.5s to recover the altitude lost during the pilot reaction time. During this encounter, the time to reach the climb rate was 11s, or 3.5s longer than expected. The achieved vertical miss distance was 73 ft.

Questions immediately arose as to why the logic did not issue an INCREASE CLIMB advisory. The logic requires a projected vertical miss distance (VMD) of less than 200 ft, true time to closest point of approach (TRTRU) values between 4 and 24s, and a tracker firmness of at least 2. The VMD and TRTRU values were sufficient for the issuance of an INCREASE RA, but the firmness was low. Both aircraft were altering their vertical speeds during this time. This raised the question of whether the firmness should be checked when issuing an INCREASE advisory, since any INCREASE advisory is caused by an extreme situation.

Questions were also raised about the 10s threshold to issue an RA REVERSAL. The 10s threshold is the expected time to execute the reversal and return to the altitude at which the REVERSAL was issued. In this particular encounter, this would have taken about 14s. It is likely that the sluggish pilot response was at least partially caused by his expectations of a very different geometry and TCAS advisories. Improved pilot response time to the advisories would have increased the vertical miss distance significantly. An INCREASE CLIMB RA would probably not have had any impact on this encounter, except perhaps to encourage the pilot to reverse more quickly, because even the standard 1500 fpm CLIMB rate was not attained until CPA.

(Note: These questions about including low firmness INCREASE advisories and an increased time threshold for reversals have been submitted to The MITRE Corporation for review through Change Request Form (CRF) No. 29. Neither of these are considered safety issues.)

RUN 7 OF JUNE 22, 1989

ENCOUNTER DESCRIPTION.

Run 7 is designed to test the INCREASE advisory logic. During this particular encounter, the run was executed as planned. However, additional traffic alerts (TAs) and RAs were issued to the pilot near the end of the encounter. These RAs were initially believed to be a malfunction of the system. However, they were actually warnings on another aircraft which had unexpectedly entered into the test airspace.

Figure C-2 is a plot of the planned encounter flight data. Figure C-3 is a plot of the unexpected target data. Figure C-4 is a composite plot showing the relationship of the two encounters. The aural advisories differed somewhat from the logic advisories. Figures C-5 and C-6 show the aural advisories posted during each run, and figure

C-7 is a composite plot of all of the aural advisories issued during both encounters.

(Note: That the aural advisories on figures C-5 through C-7 do not actually indicate which advisories were issued in response to each target. For example, the first three advisories on figure C-6 (and those same advisories on figure C-7) were in response to the planned encounter. The TA was issued due to the track drop near CPA on the planned traffic. The TA for the target of opportunity was apparently overwritten by the MAINTAIN VERTICAL SPEED advisory.)

ENCOUNTER ANALYSIS.

Much of the confusion associated with this encounter was caused by the queuing of the aural messages, the overwriting of these messages by other messages, and the failure of the Honeywell system to issue CLEAR OF CONFLICT messages. The Honeywell system frequently dropped tracks at CPA and reacquired the targets shortly thereafter, which eliminated the CLEAR OF CONFLICT message and generated an inappropriate TA.

This encounter proceeded as expected until about 33s after the initial TA was issued, when a second TA was issued, but not enunciated. The pilots had visually acquired the planned target by this time and were in the process of following an INCREASE CLIMB advisory. As a result of this activity and lack of an aural alert, the second target was not noticed on the display. The planned encounter produced a MAINTAIN CLIMB, followed by a CLIMB, followed quickly by the track drop and TA on the reacquired target. This TA was cut short by the issue of another MAINTAIN CLIMB, followed by a CROSSING CLIMB advisory. At the time, it was believed that a target split was causing this second set of advisories or that the aural generator was finishing up the queued advisories, and the pilot continued to slacken his climb rate to return to his previous altitude, thus opposing the advisory sense. The TCAS then issued a DESCEND REVERSAL advisory. At about this time, someone noticed the oncoming traffic out of the windshield, and the advisory was followed. A vertical miss distance of over 900 ft was achieved at CPA despite the poor pilot response.

Several peculiarities in the Honeywell TCAS performance contributed to the overall confusion during this run. The initial TA on the second target was never enunciated, failing to alert the pilots of the presence of the second target. The pilots had grown accustomed to the lack of hysteresis in the CLIMB and MAINTAIN CLIMB advisories, so that the initial MAINTAIN CLIMB advisory on the second target was assumed to be a queued repetition of the proceeding advisory on the first target. The pilots were also accustomed to the reacquisition of the target, and accompanying TA, after CPA. Both the surveillance software and the aural advisory software were modified after these tests.

RUNS WHICH GENERATED NEGATIVE REMARKS

The following runs generated negative remarks during the pilot questions or pilot debriefings. A plot of the flight data is included

for each run, except run 13-8. No flight data were recorded for run 13-8 because of a failure in the data recorder.

BENDIX SYSTEM.

Run 1-4 (figure C-8): The pilot was "uneasy about the separation at CPA" on this run. The separation at CPA was over 600 ft.

Run 1-7(6) (figure C-9): The pilot felt that "the soften command after an increase could have been issued earlier." The separation was over 1200 ft at CPA.

Run 1-6 (figure C-10): The pilot commented that "the last climb was inappropriate" after the MAINTAIN VERTICAL SPEED advisory. This advisory was generated because the pilot had slackened his climb rate below 1500 fpm. The pilot was also moderately concerned about the deviation form the normal flightpath. The altitude deviation on this run was about 400 ft.

Run 2-4 (figure C-11): The pilot felt that the reversal was issued too close to CPA. The reversal was issued about 19s prior to CPA, just a few seconds after the intruder aircraft leveled off. The reversal could not have been issued prior to detecting the level-off, and maintaining the original advisory would have significantly decreased the 755 ft of altitude separation at CPA.

The pilot noted an improper aural alert during this run ("DESCEND" instead of "DESCEND NOW"). This was caused by a programming error in the Bendix system.

Run 3-4B (figure C-12): The pilot noted that an extraneous VERTICAL SPEED RESTRICTED enunciation was issued with no corresponding Instantaneous Vertical Speed Indicator (IVSI) lights. This situation was noted on several occasions, and was caused by the queuing of the aural messages. This problem appeared several times during the flight tests, and resulted from the aural advisories lagging behind the IVSI lights due to the extra time required to enunciate the advisories. The Air Transport Association (ATA) now recommends terminating untimely messages immediately, and all production TCAS units do interrupt the advisories.

The pilot complained of the track drop and lack of a CLEAR OF CONFLICT message. Bendix surveillance improvements have corrected this problem.

HONEYWELL SYSTEM.

Run 6-7 (figure C-13): The pilot complained that a CLIMB advisory was issued after passing the target airplane. The advisory was actually posted in response to the slackening of the climb rate slightly before passing the target. The pilot stated that his view of the encounter was blocked by the nose of the airplane. As such, the target probably appeared to pass sooner than it actually did.

Additionally, the time required to enunciate the CLIMB advisory after the advisory was posted allowed the target to pass.

Run 8-2A (figure C-14): The pilot felt that the additional TA after CPA was very disconcerting. Honeywell surveillance improvements have corrected this problem.

Run 9-2 (figure C-15): The pilot stated that he was pretty busy during this encounter, which does not seem unreasonable when avoiding a collision. The pilot questioned the softening of the advisory from a DESCEND, stating "I'd let him go by before I stopped descending." The pilot thought that the softened command was inappropriate. The pilot then said, when asked if he was concerned about the altitude deviation, "Yes, I was. In an IFR (instrument flight rule environment), I would have talked to the Center to tell him I'm out of 12300" (the base altitude).

TCAS softens the advisory when it predicts that adequate separation will be achieved to minimize the altitude deviation. In this run, the altitude deviation was about 350 ft with an adequate altitude separation at CPA of over 600 ft.

Run 9-4 (figure C-16): The pilot complained that his workload was badly affected by the TCAS, and that he disagreed with the CLIMB command since it seemed dangerous based on his visual perception of the encounter geometry. The pilot thought a descend command would have been preferable, and that if a CLIMB command was to have been used, it should have been issued much sooner. In summing up the overall TCAS performance, he remarked "It screwed up."

The TCAS issued the CROSSING CLIMB advisory on the target when it was descending at 2000 fpm. Had the target continued at that descent rate, it would have passed below the TCAS original altitude. As such, a much greater altitude separation would have been achieved by climbing. The CLIMB advisory, or any other, would not have been issued until the target started its descent since the plane was not a threat until this time. The TCAS issued a DESCEND REVERSAL advisory shortly after the target plane leveled off, and a more than sufficient vertical miss distance of over 800 ft was achieved at CPA.

It should be noted that the revision of the 900 ft rule to the 600 ft rule would have a significant effect on this encounter.

FLIGHT TEST PLAN RUN #17

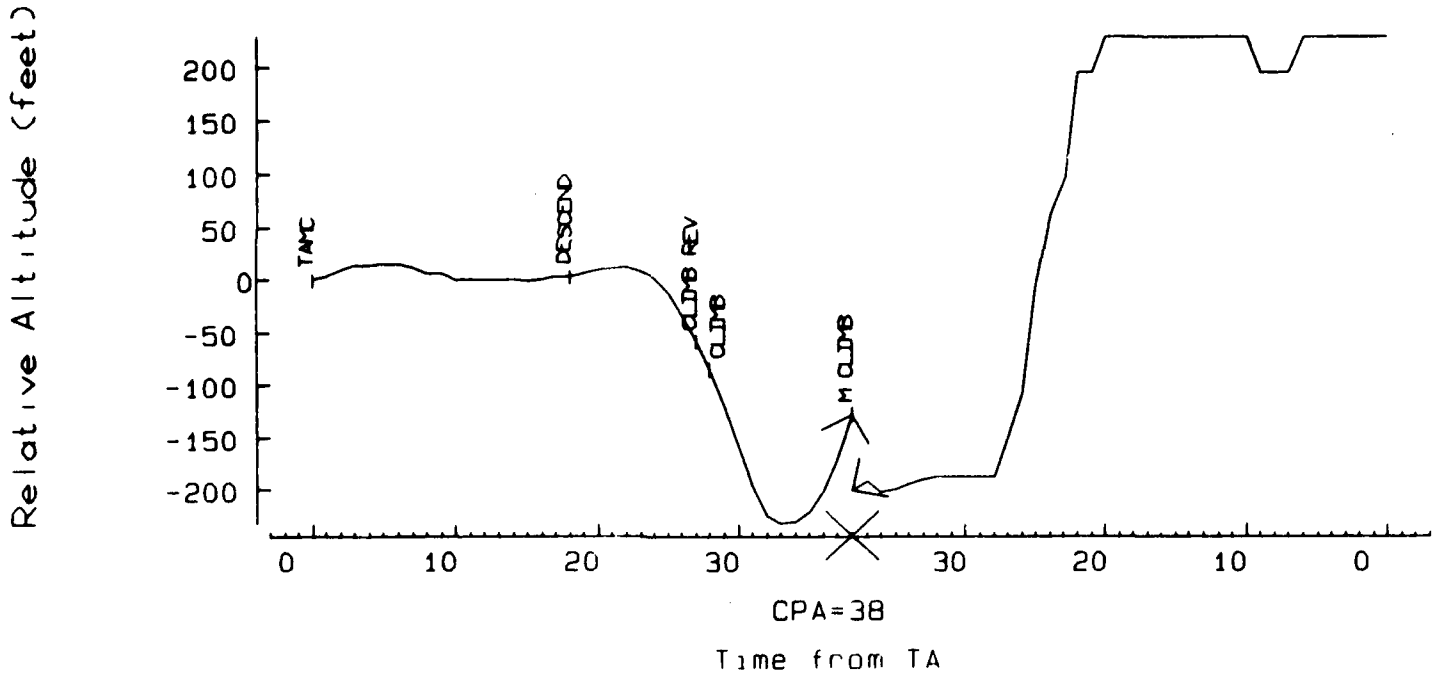
ENCOUNTER ID: 767

RANGE RATE at TA: -481

at CPA: -91

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 15:05:48

CPA TIME: 15:06:26

FLIGHT DATE: 04/17/89

VMD AT CPA: 73 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-1

PILOT EVALUATION RUN 9-4

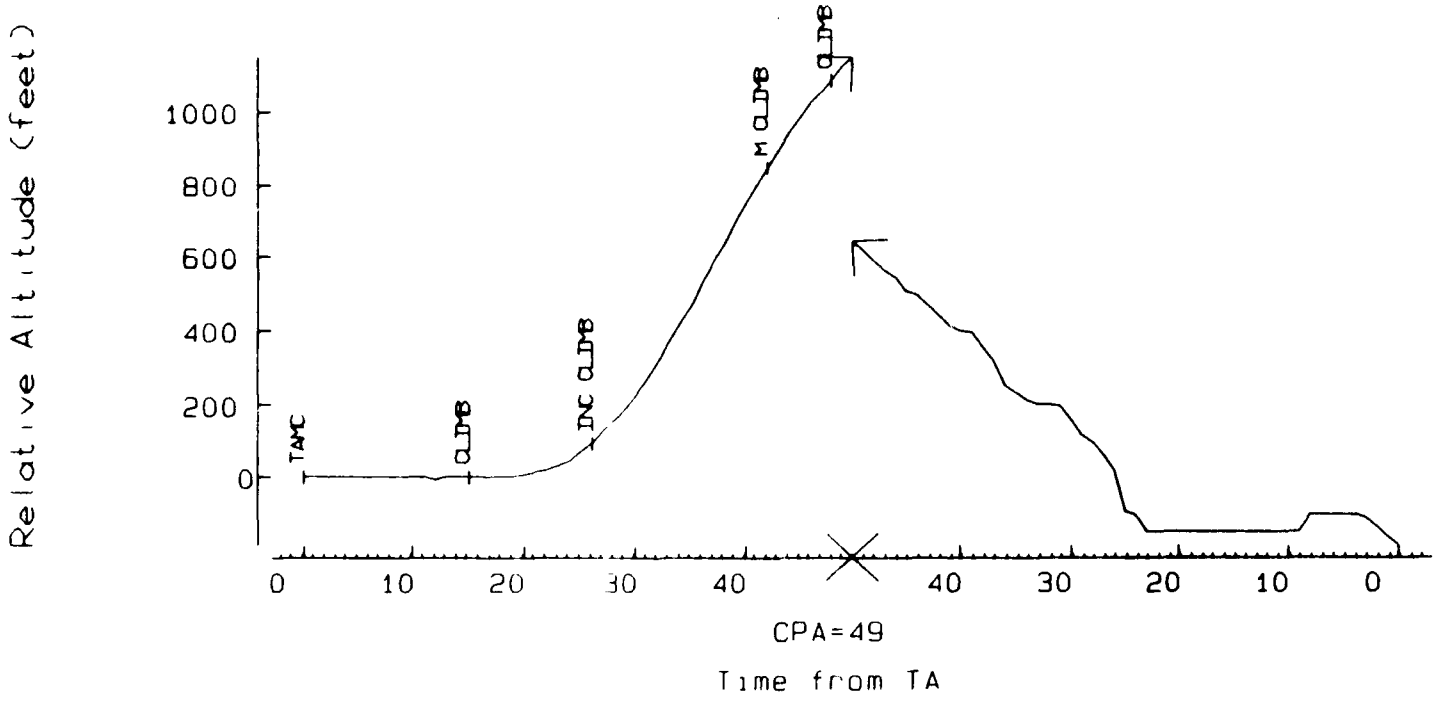
ENCOUNTER ID: 220

RANGE RATE at TA: -500

at CPA: 338

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 11:04:49

CPA TIME: 11:05:39

FLIGHT DATE: 06/22/89

VMD AT CPA: 506 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-2

TARGET OF OPPURTUNITY

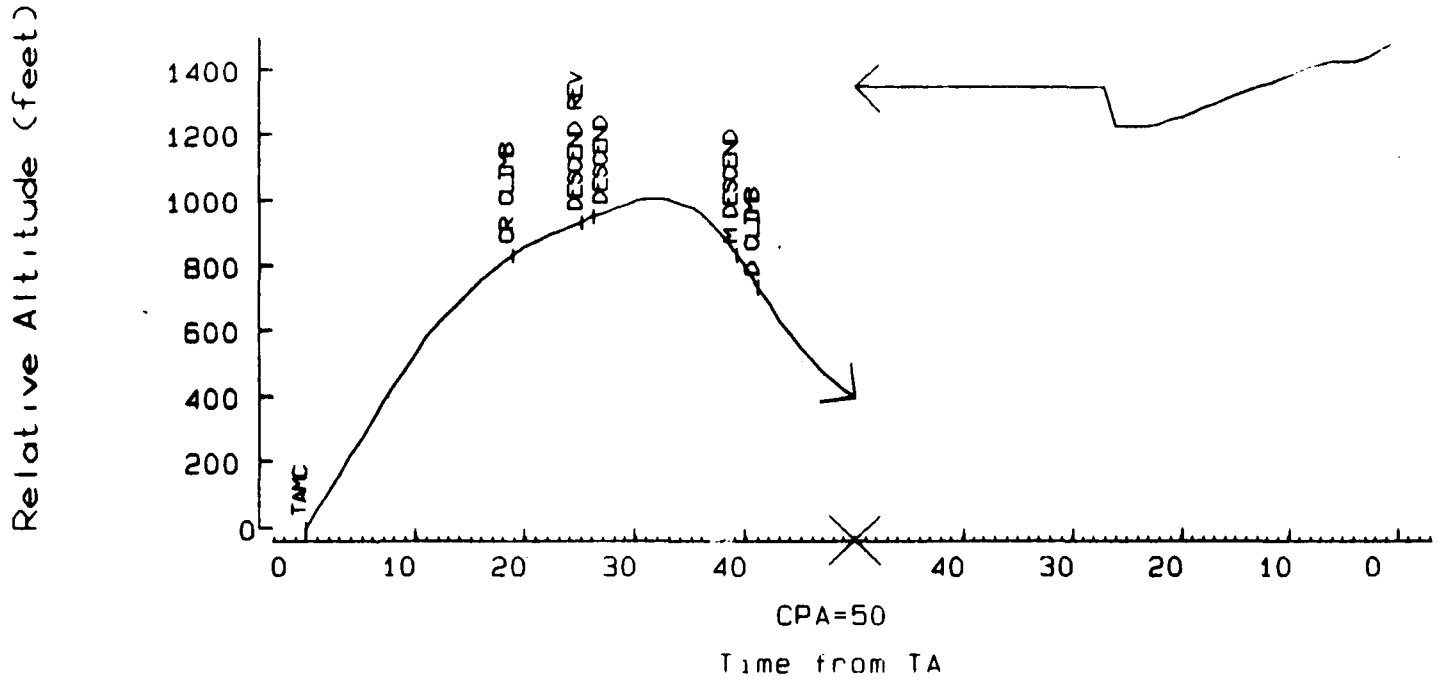
ENCOUNTER ID: 277

RANGE RATE at TA: -678

at CPA: -399

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 11:05:22

CPA TIME: 11:06:12

FLIGHT DATE: 06/22/89

VMD AT CPA: 956 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-3

TARGET OF OPPORTUNITY

TA TIME 11 05 22 CPA TIME 11 06 12

FLIGHT DATE 06/22/89 VMD AT CPA 956 ft

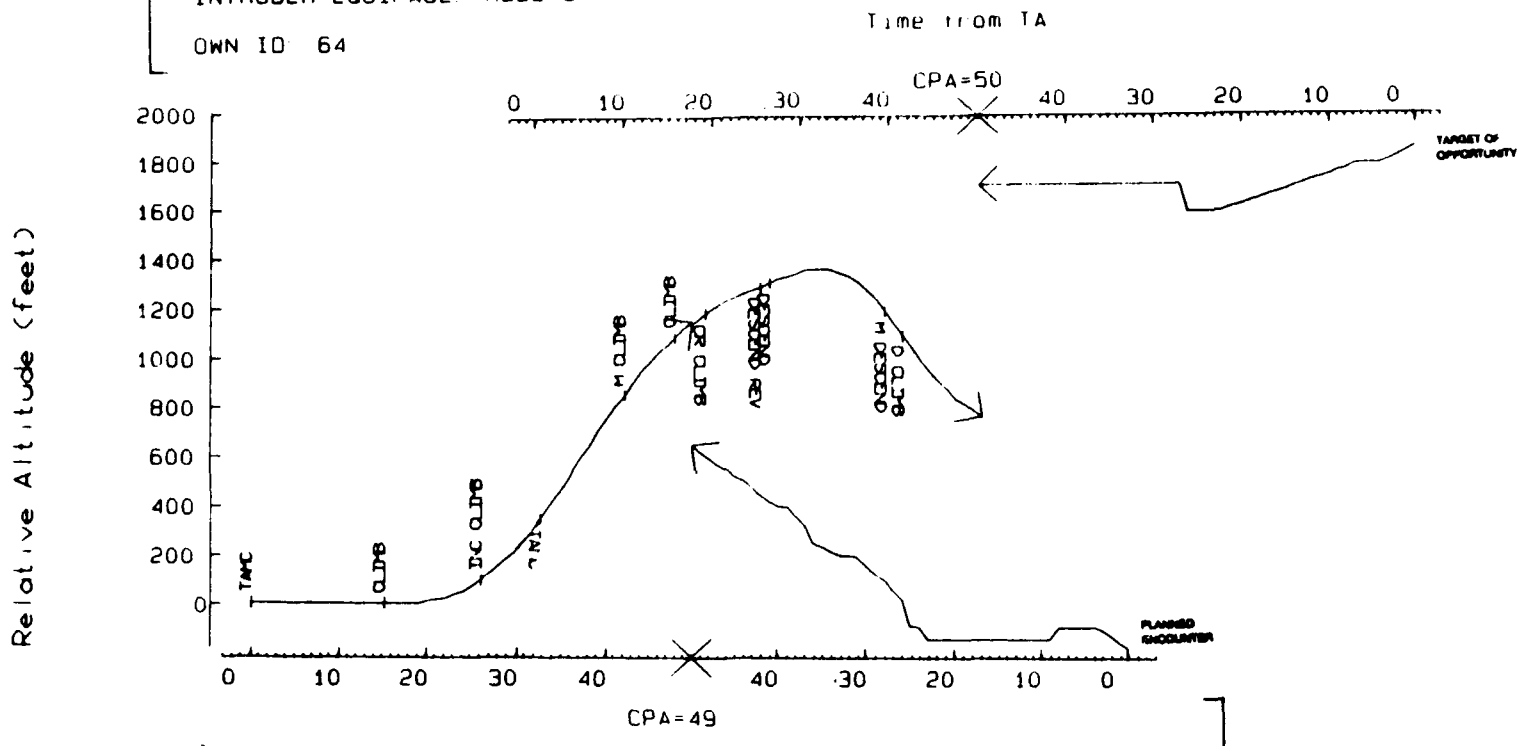
TARGET OF OPPORTUNITY

ENCOUNTER ID: 227 RANGE RATE at TA -678

at CPA -399

INTRUDER EQUIPAGE MODE C

OWN ID 64



TA TIME 11 04 49 CPA TIME 11 05 39

FLIGHT DATE 06/22/89 VMD AT CPA 506 ft

PILOT EVALUATION RUN 11-7

ENCOUNTER ID 220 RANGE RATE at TA -500

at CPA 338

INTRUDER EQUIPAGE MODE C

OWN ID 64

PLANNED ENCOUNTER

Figure C-4

PILOT EVALUATION RUN 11-7

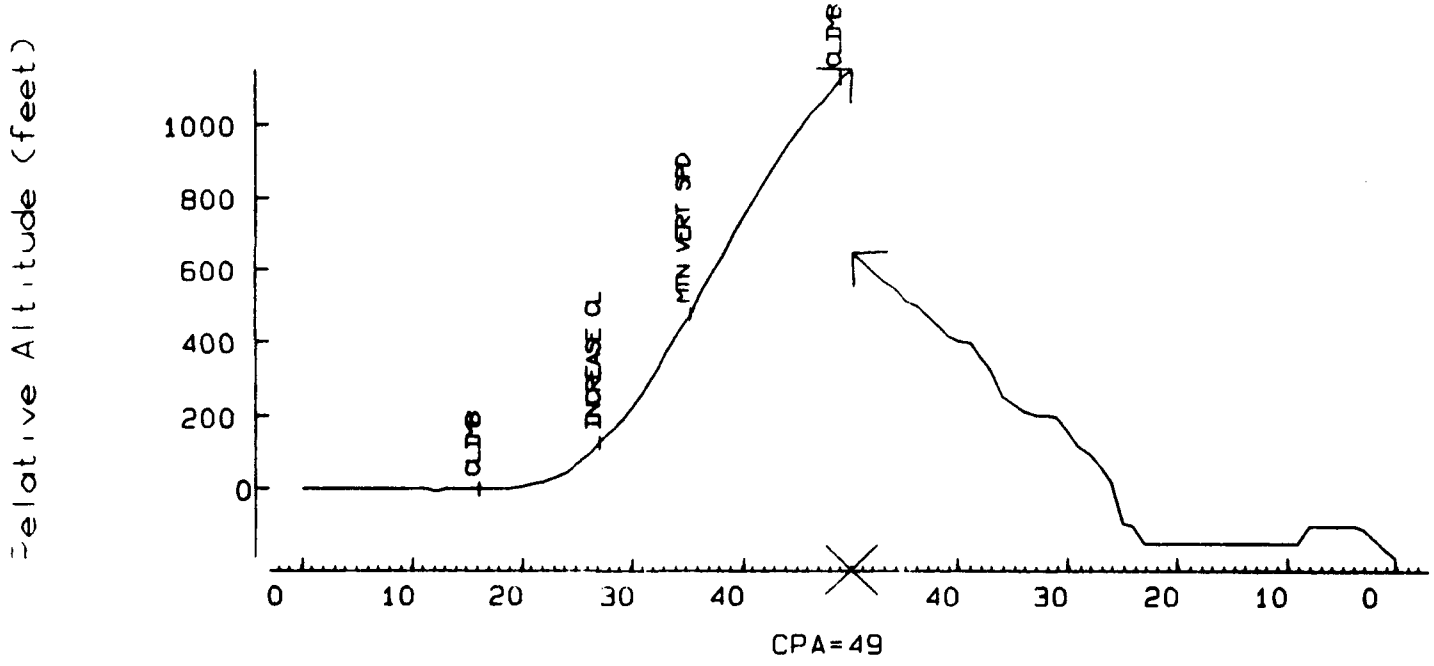
ENCOUNTER ID: 220

RANGE RATE at TA: -500

at CPA: 338

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 11:04:49

CPA TIME: 11:05:39

FLIGHT DATE: 06/22/89

VMD AT CPA: 506 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-5

TARGET OF OPPURTUNITY

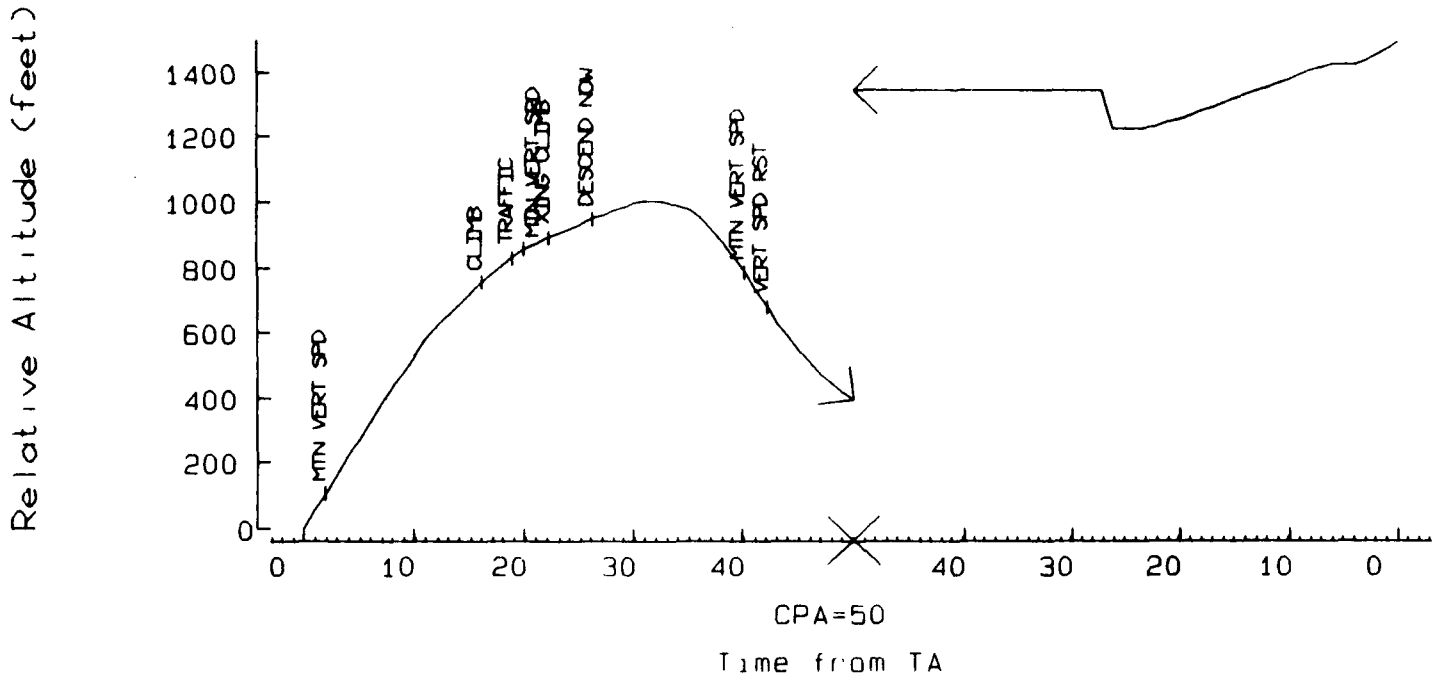
ENCOUNTER ID: 227

RANGE RATE at TA: -678

at CPA: -399

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



AURAL ADVISORIES

TA TIME: 11:05:22

CPA TIME: 11:06:12

FLIGHT DATE: 06/22/89

VMD AT CPA: 956 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-6

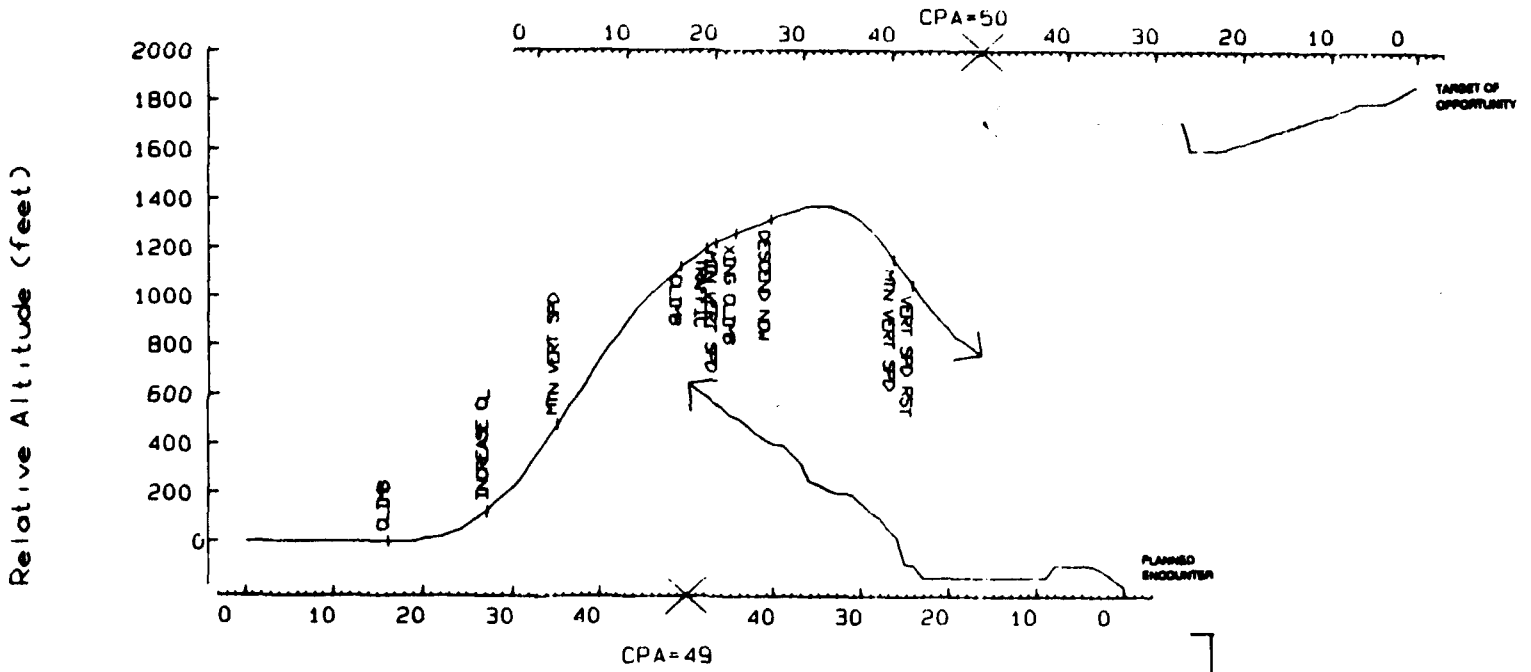
TARGET OF OPPORTUNITY

TA TIME 11 05 22
FLIGHT DATE 06/22/89
TARGET OF OPPURTUNITY
ENCOUNTER ID: 227

INTRUDER EQUIPAGE: MODE C
OWN ID: 64

CPA TIME 11 06 12
VMD AT CPA 956 ft

RANGE RATE at TA: -678
at CPA: -399



TA TIME: 11:04:49
FLIGHT DATE: 06/22/89
PILOT EVALUATION RUN 11-7
ENCOUNTER ID: 220

INTRUDER EQUIPAGE: MODE C
OWN ID: 64

CPA TIME: 11:05:39
VMD AT CPA 506 ft

RANGE RATE at TA: -500
at CPA: 338

PLANNED ENCOUNTER

Figure C-7

PILOT EVALUATION RUN 1-4

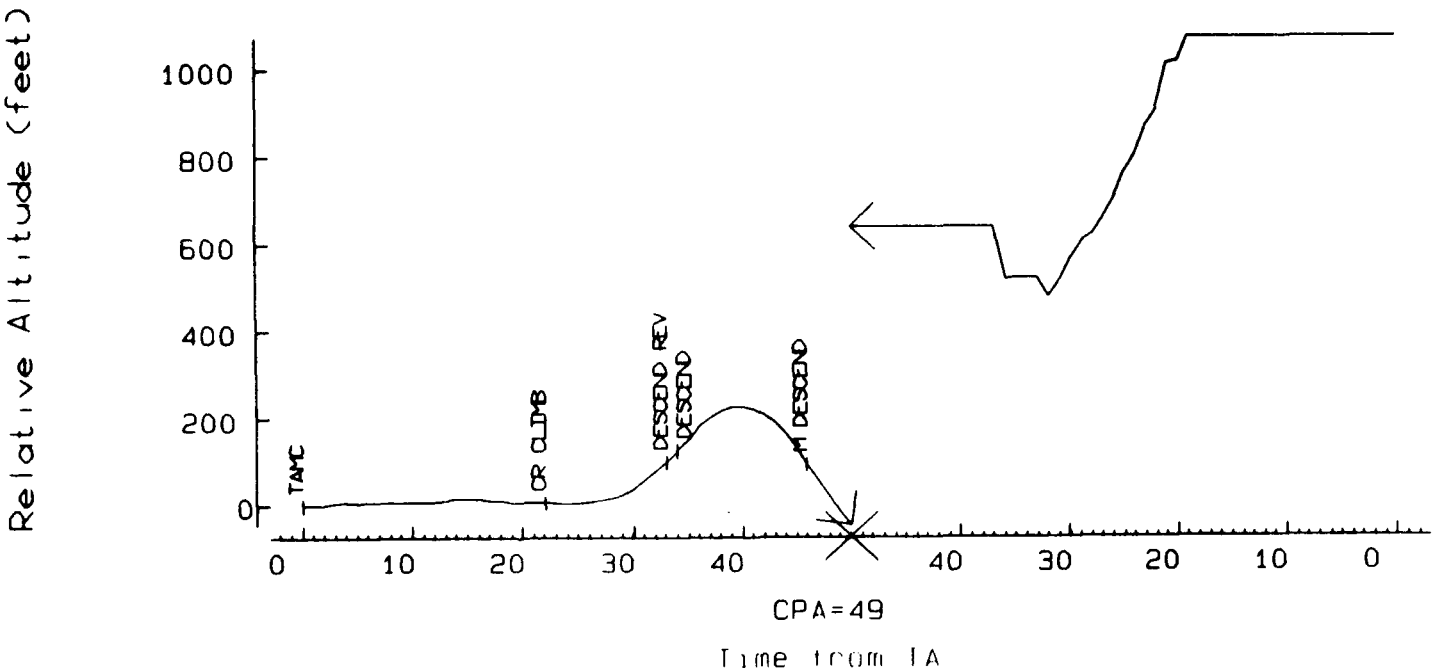
ENCOUNTER ID: 88

RANGE RATE at TA: -465

at CPA: -467

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 14:21:37

CPA TIME: 14:22:27

FLIGHT DATE: 06/06/89

VMD AT CPA: 684 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-8

PILOT EVALUATION RUN 1-7 (6)

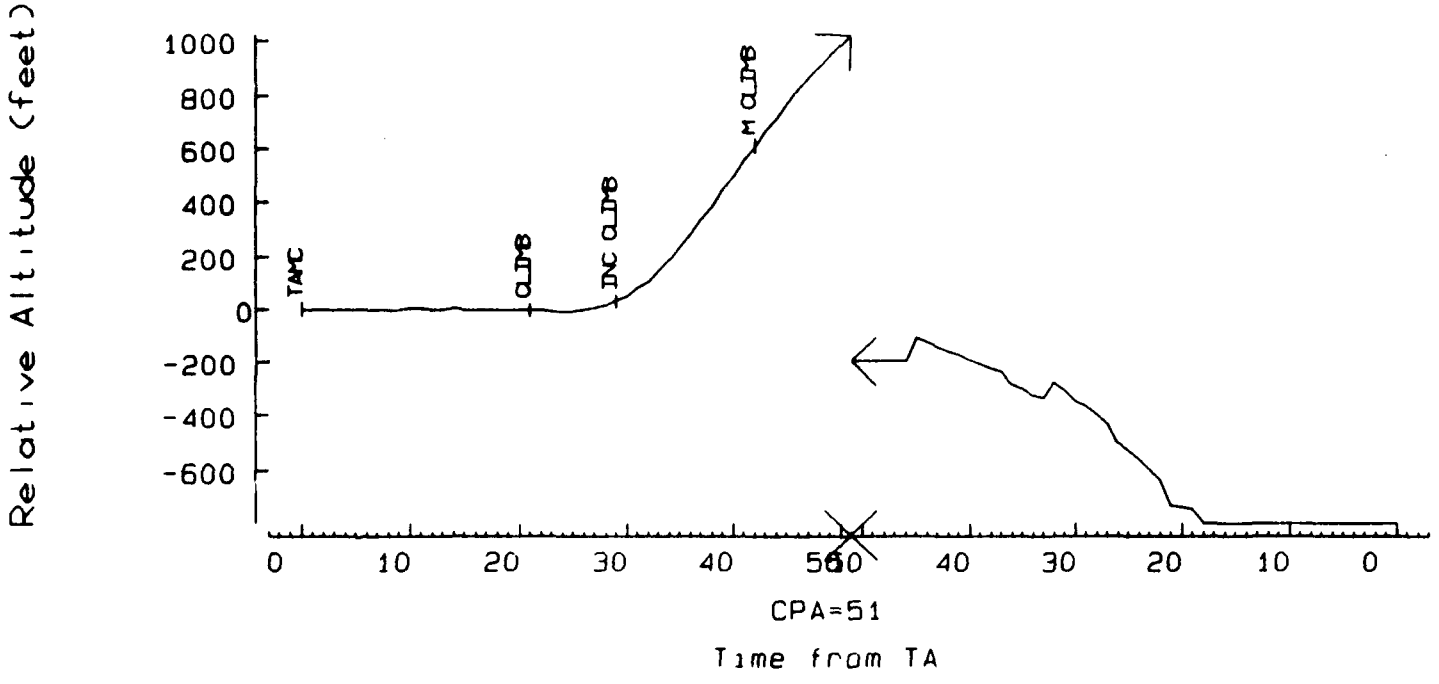
ENCOUNTER ID: 105

RANGE RATE at TA: -505

at CPA: -3957

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 14:35:20

CPA TIME: 14:36:11

FLIGHT DATE: 06/06/89

VMD AT CPA: 1221 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-9

PILOT EVALUATION RUN 1-6

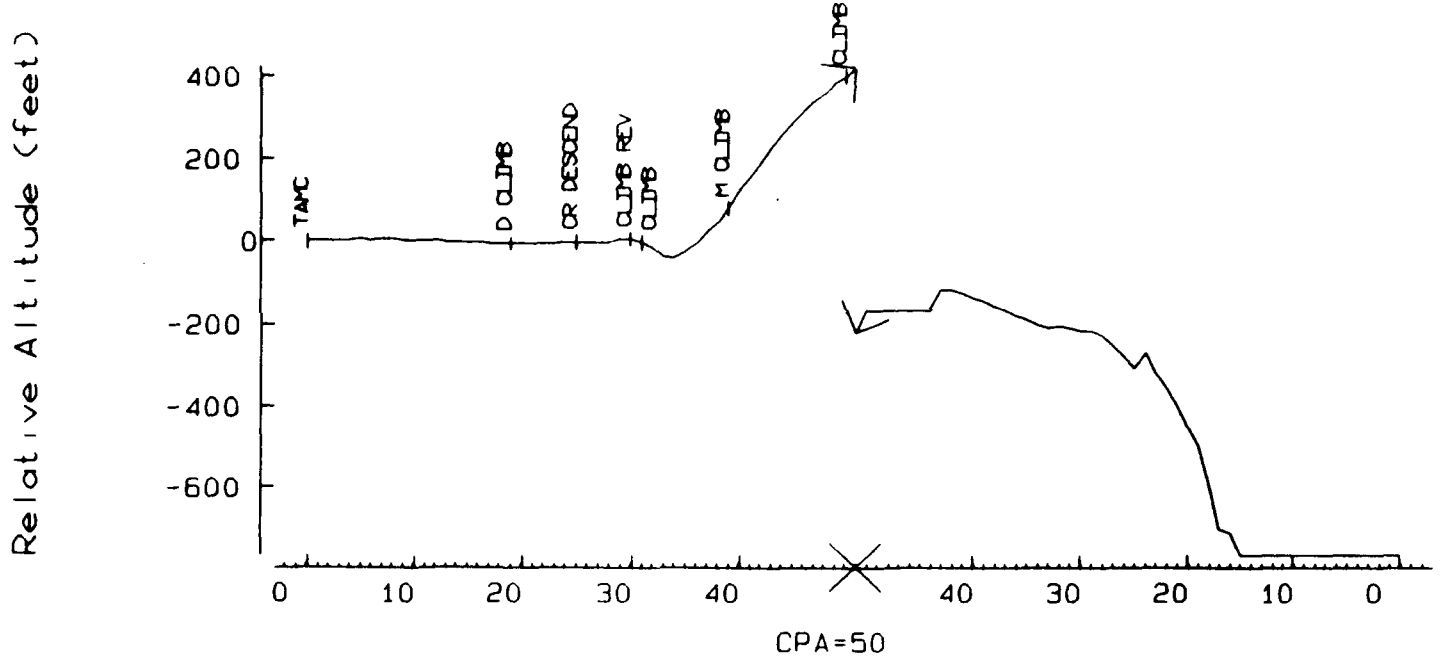
ENCOUNTER ID: 108

RANGE RATE at TA: -479

at CPA: 62

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 14:42:19

CPA TIME: 14:43:10

FLIGHT DATE: 06/06/89

VMD AT CPA: 644 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-10

PILOT EVALUATION RUN 2-4

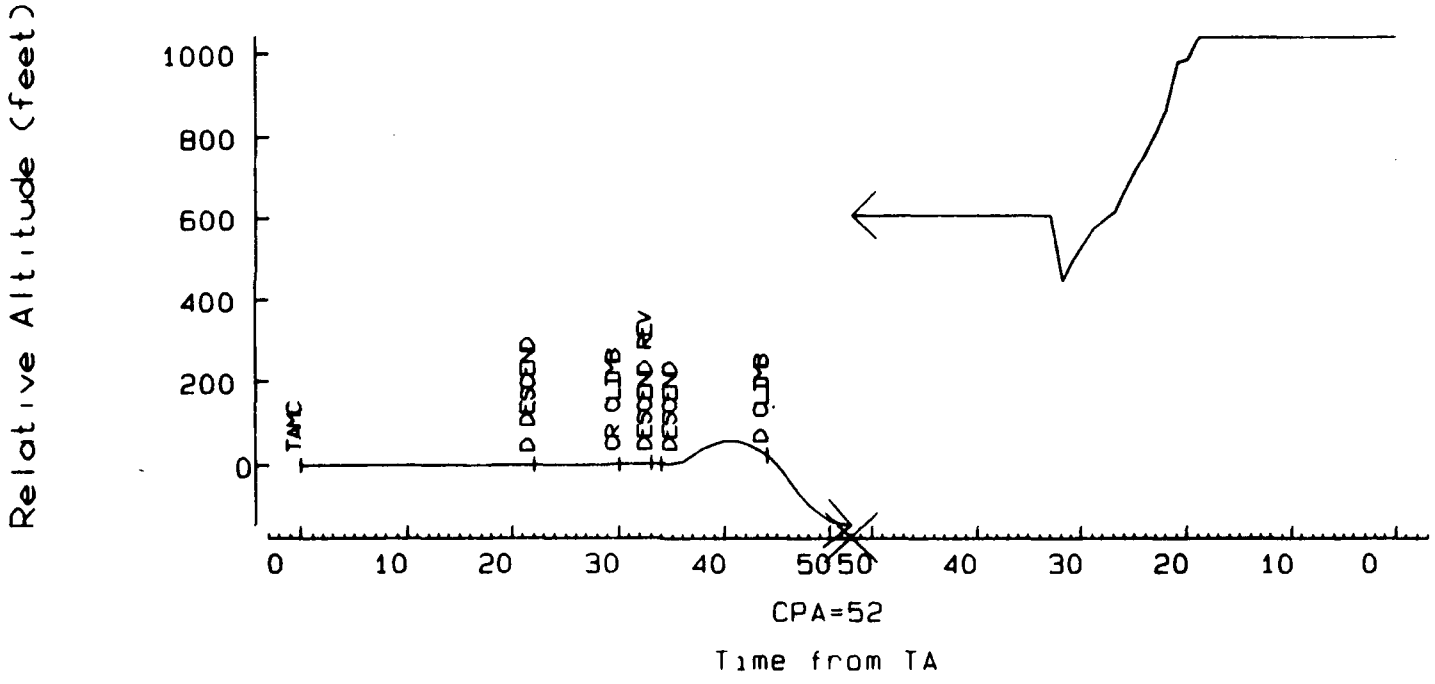
ENCOUNTER ID: 164

RANGE RATE at TA: -458

at CPA: -410

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 15:09:30

CPA TIME: 15:10:22

FLIGHT DATE: 06/06/89

VMD AT CPA: 755 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-11

PILOT EVALUATION TUN 3-48

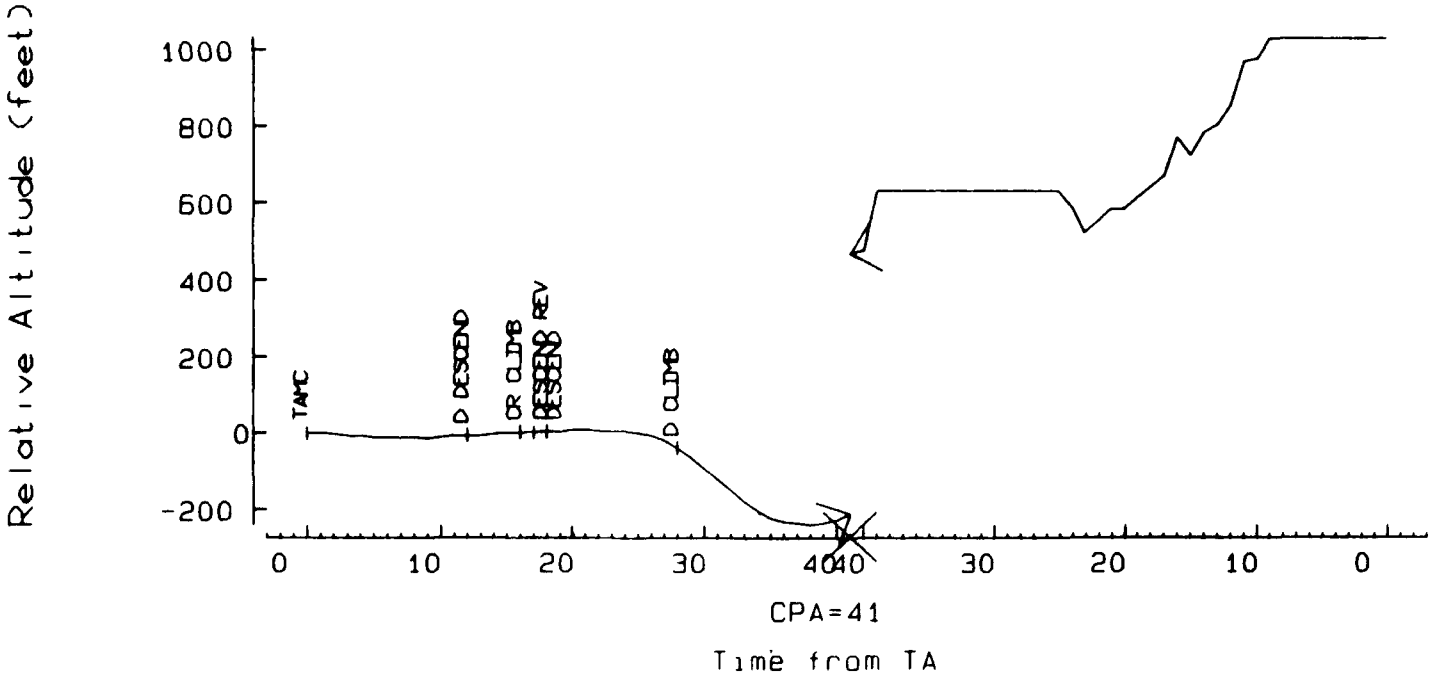
ENCOUNTER ID: 214

RANGE RATE at TA: -440

at CPA: -209

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 15:43:42

CPA TIME: 15:44:23

FLIGHT DATE: 06/06/89

VMD AT CPA: 679 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-12

PILOT EVALUATION RUN 6-7

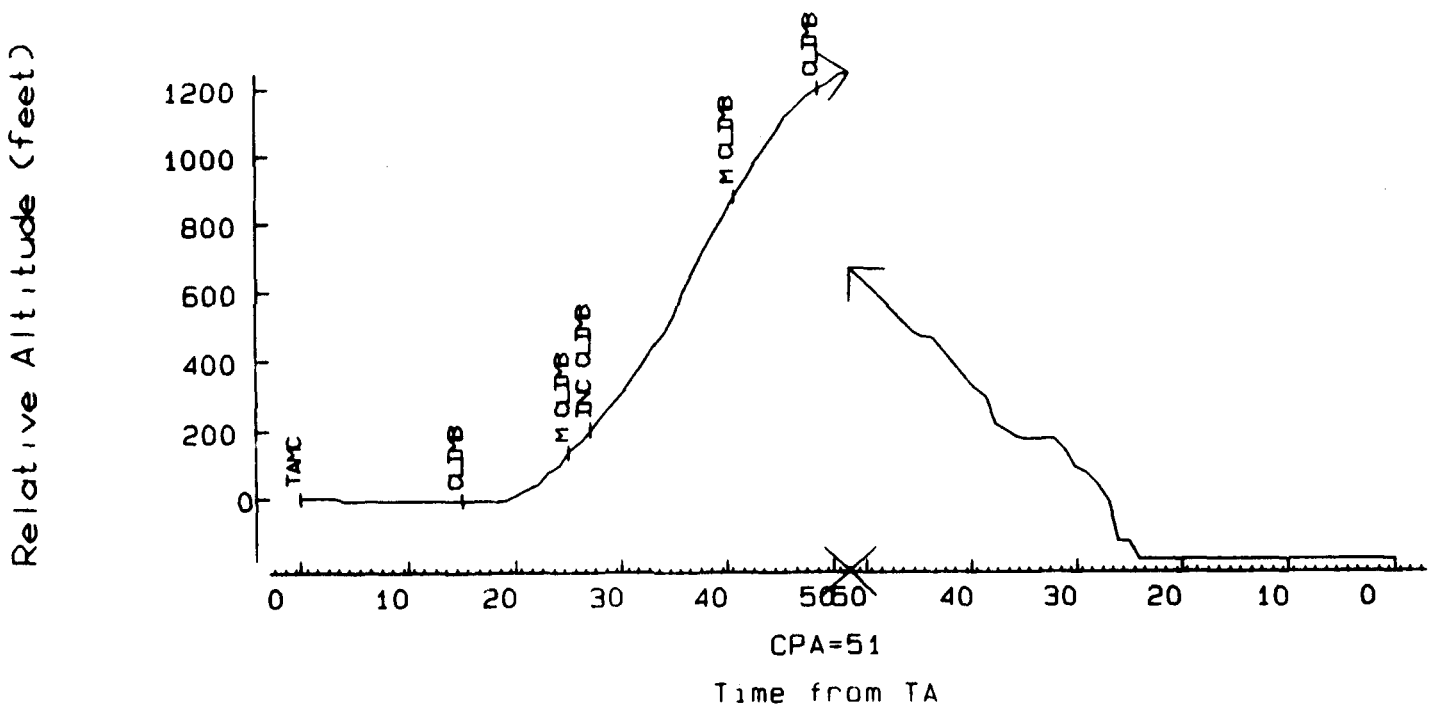
ENCOUNTER ID: 454

RANGE RATE at TA: -494

at CPA: 251

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 11:33:44

CPA TIME: 11:34:36

FLIGHT DATE: 06/19/89

VMD AT CPA: 575 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-13

PILOT EVALUATION RUN 8-2A

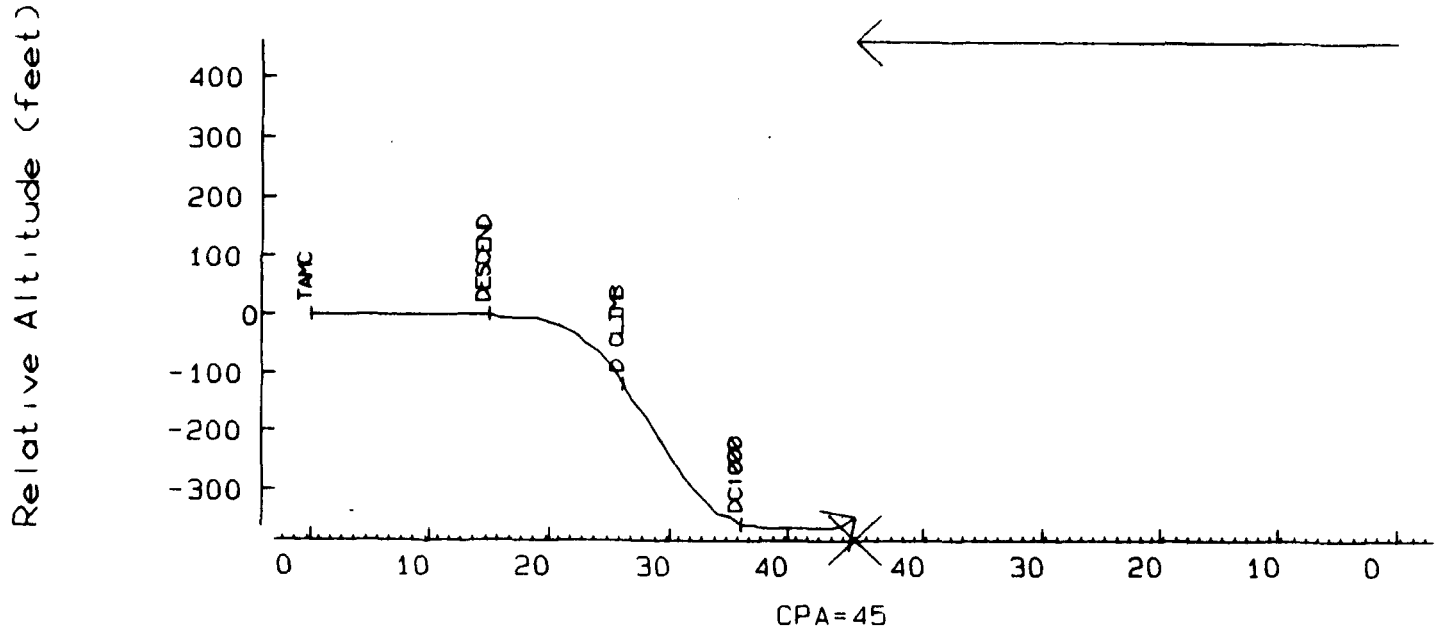
ENCOUNTER ID: 616

RANGE RATE at TA: -456

at CPA: -431

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 12:23:21

CPA TIME: 12:24:07

FLIGHT DATE: 06/19/89

VMD AT CPA: 806 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-14

PILOT EVALUATION RUN 9-2

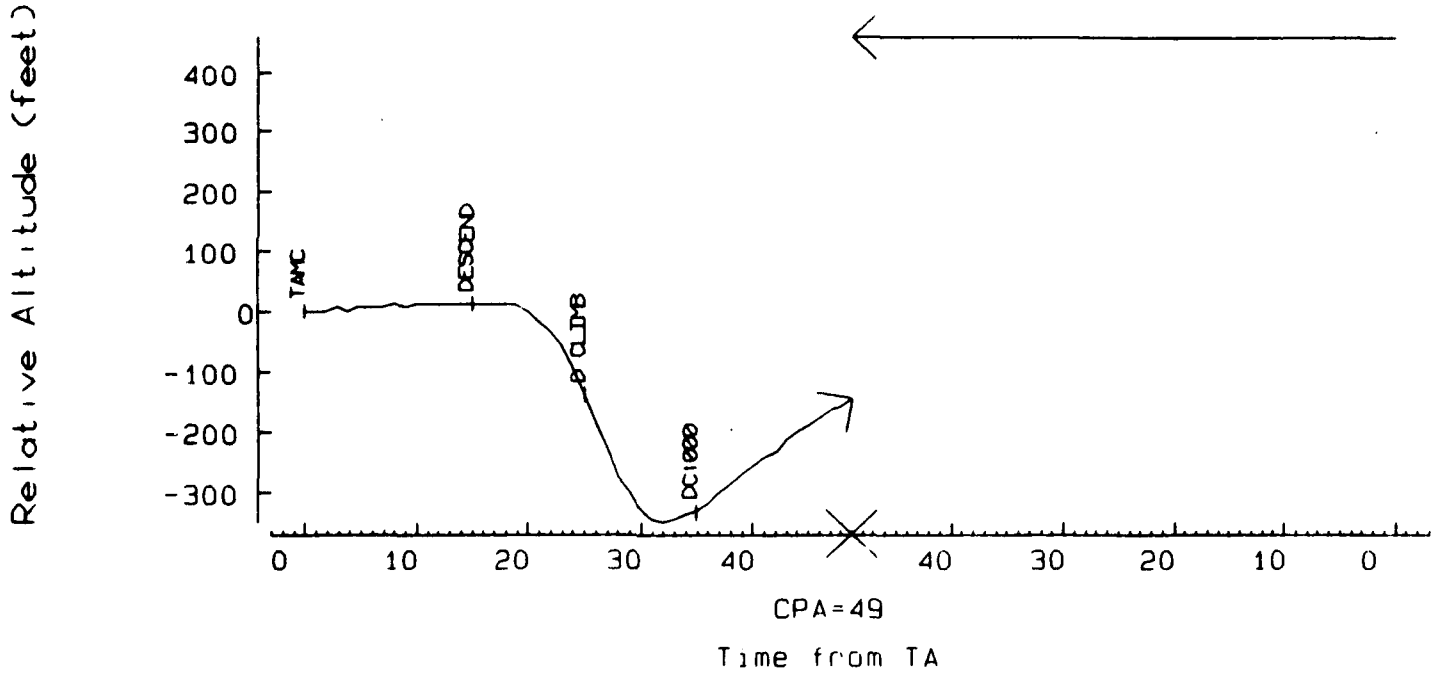
ENCOUNTER ID: 117

RANGE RATE at TA: -459

at CPA: -312

INTRUDER EQUIPAGE: MODE C

OWN ID: 64



TA TIME: 10:48:25

CPA TIME: 10:49:14

FLIGHT DATE: 06/20/89

VMD AT CPA: 606 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-13

PILOT EVALUATION RUN 9-4

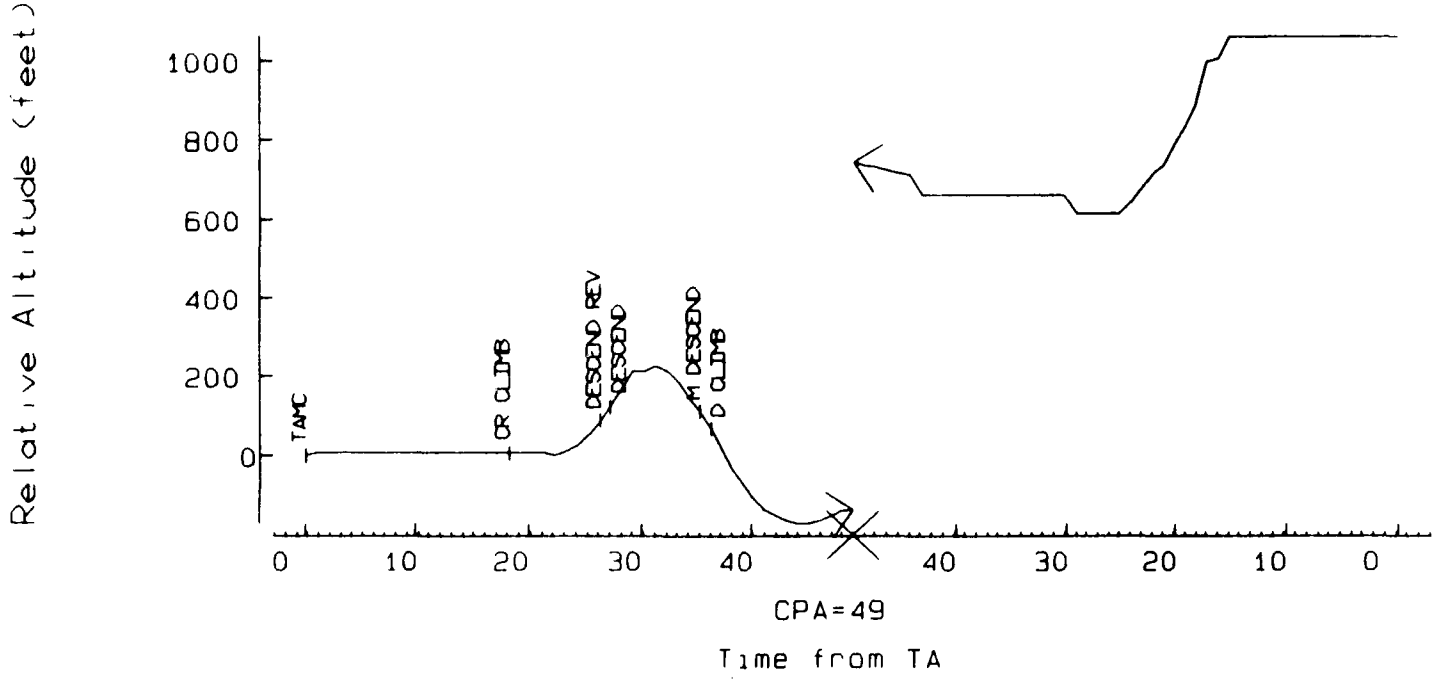
ENCOUNTER ID: 140

RANGE RATE at TA: -472

at CPA: -293

INTRUDER EQUIPAGE: MODE C

OWN ID 64



TA TIME: 11:01:03

CPA TIME: 11:01:52

FLIGHT DATE: 06/20/89

VMD AT CPA: 881 ft

PROCESSED ON: 09/20/90 by ACD-320 FAA Technical Center

Figure C-16

APPENDIX D

FLIGHT DATA SUMMARIES

TABLE D-1. CHANGE 6 VALIDATION FLIGHTS

System: Bendix

Date	Aircraft	Data Collected
4/13/89	B727	System checkout
4/17/89	B727	Runs 1-17
4/18/89	B727	Runs 1-17
4/20/89	B727	Runs 5,6,16 and 17
5/02/89	B727	Runs 18-24 (coordination)
	Sabreliner	Runs 18-24 (coordination)
6/05/89	B727	Atlanta en route data
6/06/89	B727	Runs 2,4,6,7,8 and 12 (pilot evaluation)
6/08/89	B727	Runs 2,4,6,7,8 and 12 (pilot evaluation)
6/13/89	Sabreliner	Runs 18-24 (coordination)
6/16/89	B727	Runs 18-24 (coordination)

Total Bendix System Flights: 11

System: Honeywell

Date	Aircraft	Data Collected
6/12/89	B727	System checkout
6/13/89	B727	Runs 18-24 (coordination)
	Kingair	Runs 18-24 (coordination)
	B727	Runs 18-24 (coordination)
6/14/89	B727	Runs 1-17
6/15/89	B727	Runs 2-17
6/16/89	Kingair	Runs 18-24 (coordination)
6/19/89	B727	Runs 2,4,6,7,8 and 12 (pilot evaluation)
6/20/89	B727	Runs 2,4,6,7,8 and 12 (pilot evaluation)
6/22/89	B727	Runs 2,4,6,7,8 and 12 (pilot evaluation)
6/23/89	B727	Runs 2,4,6,7,8 and 12 (pilot evaluation)

Total Honeywell System Flights: 11

TABLE D-2. SUMMARY OF TCAS/MODE C FLIGHT DATA BY ENCOUNTER

Encounter Type: Logic Tested	Encounter Number	Number of Runs by System		Total Runs of Each Encounter
		Bendix	Honeywell	
Head-ons:	1	3	15	18
	2	12	20	32
Descend inhibit	15	3	1	4
				54
Altitude Crossings:				
Increase Rate	7	6	11	17
	8	7	10	17
Increase/Reverse	9	2	2	4
	10	3	1	4
<10s to Reverse	14	12	8	20
Incr Desc Inhibit	16	5	-	5
	17	3	-	3
				70
Vertical Fake-outs:				
Reverse	3	3	1	4
	4	13	18	31
	5	9	2	11
	6	15	10	25
900-ft Rule	13	2	3	5
				76
Tail Chase:				
	11	2	1	3
	12	8	10	18
				21
Total TCAS/MODE C Runs Performed		108	113	221

TABLE D-3. SUMMARY OF TCAS/TCAS FLIGHT DATA BY ENCOUNTER

Encounter Type: Logic Tested	Encounter Number	Number of Runs by System Bendix	Honeywell	Total Runs of Each Encounter
Head-ons:				
	18	4	7	11
	19	4	4	8
				19
Altitude Crossings:				
Increase Rate	20	4	6	10
	21	4	4	8
	22	4	4	8
	23	6	5	11
				37
Vertical Fake-outs:				
Level Wait	24	4	4	8
Total TCAS/TCAS Runs Performed		30	34	64

Total Runs from TCAS/MODE C Testing	221
Total Runs from TCAS/TCAS Testing	64
Total Number of Runs Performed	285

NOTE: Data loss occurred while using both systems during the flight tests. Data from 32 of the 285 runs was lost.

TABLE D-4. SUCCESS OF ENCOUNTERS IN GENERATING INVALID ADVISORY ALTERNATIVE RAs (IAARAs)

Note: This data is summarized only from the pilot evaluation phase of the flight test, as this was the only section of flight testing which involved many repetitions of the same encounters.

Encounter	Success as Simulated	Success in Generating Any IAARA
4 (reversal)	13 of 21 runs (62%)	14 of 22 runs (64%)
6 (reversal)	9 of 21 runs (43%)	14 of 21 runs (67%)
7 (increase)	7 of 10 runs (70%)	
8 (increase)	5 of 8 runs (63%)	

Success as simulated indicates that the advisories for a particular repetition were the same (or at least of the same sense) as the simulation used for the encounter drawing. Success in generating any IAARA indicates that some IAARA, either an Increase Rate or Reversal, was generated during a particular repetition due to variation in the encounter geometry. All runs which generated IAARAs were used in the pilot evaluation, as the goal was for each pilot to experience climb and descend sense increases and reversals.

TABLE D-5. EXPECTED AND ACTUAL ALTITUDE SEPARATIONS AND DEVIATIONS BY ENCOUNTER (IN FEET)

Notes: The maximum altitude deviation often occurs after CPA. This is especially true for those encounters with positive advisories still posted at CPA.

Signed altitude deviations are included for those runs with RA reversals. The maximum deviation in each direction is included.

* Indicates that this information was unavailable from the processed data. For some encounters, only summary data printouts were available when generating this table, and the maximum deviations were not always included in the summary. In the bulk of the encounters, the maximum deviation was after CPA, and the TCAS unit dropped the track near CPA (see Results of Pilot Debriefings).

man Indicates that the airplane was maneuvering at the time the advisory was issued. The altitude deviations are calculated from the highest (or lowest) altitude achieved by the plane as the maneuver was arrested from following the TCAS advisory (i.e., A climbing plane receives a DESCEND advisory. The plane continues to climb (at a decreasing rate) while accelerating to follow the descend advisory. The altitude deviation is calculated using the highest altitude achieved as the point of deviation).

The runs have been grouped by encounter number because of the similarity of the initial geometries. The variations in the resulting advisories due to variations in the encounter geometries can be easily seen.

Not all performed encounters are included in this chart. Those encounters in which the pilot ignored the advisories were deleted. The poor performance of the data recorders was also responsible for a considerable number of lost encounters.

RA List Abbreviations:

DCL = Don't Climb	DDES = Don't Descend
CL = Climb	DES = Descend
ICL = Increase Climb	IDES = Increase Descent
LC5 = Limit Climb to 500 fpm	LD5 = Limit Descent to 500 fpm
LC1 = Limit Climb to 1000 fpm	LD1 = Limit Descent to 1000 fpm
LC2 = Limit Climb to 2000 fpm	LD2 = Limit Descent to 2000 fpm

TABLE D-5. EXPECTED AND ACTUAL ALTITUDE SEPARATIONS AND DEVIATIONS BY ENCOUNTER (IN FEET) (CON'T)

Run Number	Altitude Separation at CPA	Altitude Deviation at CPA	Maximum Altitude Deviation	RA List
		Encounter 2		
Expected	750	350	360	DES/DCL/LC1
2	693	291	423	DES/DCL/LC1
1-2A	790	415	425	DES/DCL/LC2
2-2	849	457	497	DES/DCL/LC2
3-2	736	240	366	DES/DCL/LC2
3-2A	743	299	*	DES/DCL
5-2	951	532	676	DES/LC2
2	919	363	*	DES/LC5/LC2
2	912	443	443	DES/DCL/LC1/LC2
6-2	806	219	319	DES/DCL/LC1
6-2A	756	394	400	DES/DCL/LC1
7-2	269	413	469	DES/DCL/LC1
8-2A	806	344	363	DES/DCL/LC1
9-2	606	144	350	DES/DCL/LC1
9-2A	744	300	388	DES/DCL/LC1
11-2	894	463	513	DES/DCL/LC2
11-2A	1094	657	669	DES/DCL/LC2
12-2	806	362	381	DES/DCL/LC2
13-2A	700	238	313	DES/DCL/LC1

TABLE D-5. EXPECTED AND ACTUAL ALTITUDE SEPARATIONS AND DEVIATIONS BY ENCOUNTER (IN FEET) (CON'T)

Run Number	Altitude Separation at CPA	Altitude Deviation at CPA	Maximum Altitude Deviation	RA List
		Encounter 4		
Expected	750	150	+186/-152	CL/DES/DCL
4	642	321	*	CL/DES
4	757	-256	+251/-*	CL/DES
4	920	316	429	DES/LC1/LC2
4	936	404	406	DDES/CL/DES/LC5
4	904	-249	+157/-*	CL/DES/DCL
1-4	686	-45	+225/-*	CL/DES
2-4	766	-145	+55/-145	DDES/CL/DES/DCL
3-4	1030	396	396	DES/LC1
3-4A	967	283	306	DES/LC5
3-4B	689	-210	+0/-240	DDES/CL/DES/DCL
3-4C	741	-248	+184/-277	CL/DES/DCL
4-4	844	-290	+57/-290	CL/DES/LC5
5-4	823	-211	+113/-*	CL/DES/DCL
4	963	-319	+300/-319	CL/DES/LC5
6-4	987	343	343	DES/LC1
6-8 (4A)	1269	638	819	DES/IDES/LC2
6-4B	906	219	319	DES/LC5/LC2
6-4C	1012	-412	+75/-470	CL/DES/LC2
8-4A	719	-213	+262/-*	CL/DES/IDES
9-4	881	-138	+225/-175	CL/DES/DCL
10-4	1087	294	450	DES/DCL/LC2
10-4A	950	-325	+88/-350	CL/DES/LC5/LC2
11-4	1144	-469	+50/-469	CL/DES/LC5/LC2
12-4A	962	325	332	DES/DCL
12-4B	981	-306	+138/-306	CL/DES/LC5/LC2
13-4	888	-257	+143/-300	CL/DES/DCL/LC2
		Encounter 5		
Expected	653	253	+161/-342	CL/DES
5	554	356	*	DDES/DES
5	566	-283	+304/-*	CL/DES
5	714	432	*	DES/DCL
5	655	434	*	DDES/CL/DES
5	653	276	466	DES/DCL/LC2
5	906	568	573	DES/LC5
5	1007	720	739	DCL/DES/IDES /DES/DCL
5	598	328	400	DES/DCL
5	775	-312	+75/-312	CL/DES/DCL

TABLE D-5. EXPECTED AND ACTUAL ALTITUDE SEPARATIONS AND DEVIATIONS BY ENCOUNTER (IN FEET) (CON'T)

Run Number	Altitude Separation at CPA	Altitude Deviation at CPA	Maximum Altitude Deviation	RA List
		Encounter 6		
Expected	653	253	-157/+352	DES/CL/DDES
6	283	517	*	DES
6	316	449	*	DES
6	659	+416	-74/+420	DES/CL/LD1
6	634	765	*	DES/IDES/DES
6	749	489	504	CL/DDES
6	665	+453	-146/+459	DES/CL/DDES
6	723	+587	-27/+*	DES/CL/DDES
1-8 (6)	353	554	*	DES/IDES
1-7 (6A)	1225	1026	*	CL/ICL/CL
1-6B	645	+424	-40/+493	DCL/DES/CL
3-6A	518	689	*	DES
3-6B	729	527	527	CL/DDES
3-6C	309	488	*	DES/IDES
4-8 (6)	378	596	*	DES/IDES
4-8A (6A)	568	598	*	DES/IDES
4-6B	738	+314	-239/+314	DES/CL/DDES
5-6	701	+289	-62/+298	DES/CL/DDES
6	650	412	*	DES/CL/DDES
6-6	894	469	519	DCL/CL/DDES/LD2
8-6	813	475	612	CL/DDES/LD2
8-6A	963	+631	-19/+631	DCL/DES/CL/DDES
8-6	775	544	650	DCL/CL/DDES
10-6	750	462	469	CL/DDES
10-6A	819	494	*	CL/DDES/LD1
11-6	781	+431	-150/+*	DES/CL/DDES
12-6	581	+225	-293/+*	DES/CL
13-7 (6)	894	531	675	CL/ICL/LD5/LD2
13-6A	975	637	637	CL/DDES

TABLE D-5. EXPECTED AND ACTUAL ALTITUDE SEPARATIONS AND DEVIATIONS BY ENCOUNTER (IN FEET) (CON'T)

Run Number	Altitude Separation at CPA	Altitude Deviation at CPA	Maximum Altitude Deviation	RA List
		Encounter 7		
Expected	257	890	1386	CL/ICL/CL
7	270	876	*	CL/ICL
3-7	305	908	*	CL/ICL
4-7	239	987	*	CL/ICL
5-7	494	1106	*	CL/ICL
7	631	1319	*	CL/ICL/CL
6-7	575	1244	*	CL/ICL/CL
8-7	225	694	*	CL
8-7A	794	631	675	CL/DDES/LD2
9-7	725	1407	*	CL/ICL/CL
10-7	519	1407	*	CL/ICL/CL
12-7	450	1163	1344	CL/ICL/CL
		Encounter 8		
Expected	257	890	1386	DES/IDES/DES
8	183	884	*	DES/IDES
8	314	685	*	DES
3-8	381	907	*	DES/IDES
5-8	358	734	1312	DES/IDES
8	625	1150	*	DES/IDES/DES
9-8	531	1050	*	DES
10-8	682	1137	1400	DES/IDES/DES
11-8	537	1181	*	DES/IDES/DES
12-8	162	718	*	DES
12-8A	625	1206	*	DES/IDES/DES
		Encounter 10		
Expected	376	876	1330	DCL/DES/IDES /DES
10	466	765	*	DCL/DES/IDES
10	357	563	*	DES

TABLE D-5. EXPECTED AND ACTUAL ALTITUDE SEPARATIONS AND DEVIATIONS BY ENCOUNTER (IN FEET) (CON'T)

Run Number	Altitude Separation at CPA	Altitude Deviation at CPA	Maximum Altitude Deviation	RA List
		Encounter 12		
Expected	361	1874	2870	DES/IDES
12	311	1433	*	DES/CL/DES
12	235	554	*	DES
1-12	364	576	*	DES
3-12	370	575	*	DES
4-12	501	856	*	DES
5-12	388	812	*	DES
12	894	1719	*	DES/DCL
6-12	607	-1232	+175/-*	CL/DES/DCL/DES
9-12	975	2030	*	DES/DCL/DES
10-12	581	1531	1887	DCL/DES/DCL/DES
11-12	731	1175	1900	DES/DCL/DES/LC5 /DCL/DES
12-12	525	1019	2225	DES
		Encounter 13		
Expected	1150	250	260	DES/LC1/LC2
13	1065	315	366	DES/LC1
13	1056	556	*	DES
		Encounter 14		
Expected	324	724	1220	CL/ICL
14	753	459	*	DES/IDES/DES
14	666	725	*	CL/LD1
14	975	731	*	DES/IDES/LC5
14	270	-140	+319/-*	CL/DES/IDES
14	652	662	*	CL
14	563	387	389	DES
14	446	687	687	CL
14	240	462	557	CL/ICL
14	750	-356	+287/-394	CL/DES/LC5
14	587	368	381	DES/LC5
10-14A	919	463	525	DES/LC2

TABLE D-5. EXPECTED AND ACTUAL ALTITUDE SEPARATIONS AND DEVIATIONS BY ENCOUNTER (IN FEET) (CON'T)

Run Number	Altitude Separation at CPA	Altitude Deviation at CPA	Maximum Altitude Deviation	RA List
		Encounter 15		
Expected	559	359	385	DES/DCL
15	427	290	327	DES/DCL
15	654	375	375	DES/DCL
15	631	356	388	DES/DCL
		Encounter 16		
Expected	366	516	1011	DES/IDES
16	494	374	394	DES
16	364	631	794	DES/IDES/DES
16	563	156	156	DES/DCL
16	330	562	*	DES/IDES
		Encounter 17		
Expected	186	336	610	DES
17	313	339	*	DES
		Encounter 19		
Expected /plane 1	1025	325	335	DES/LC2
\plane 2	1025	325	335	CL/LD2
19 /plane 1	1411	270	331	DES/LC2
\plane 2	1441	522	633	CL/DDES
19 /plane 1	1062	293	340	DES/LC2/LC1/LC2
\plane 2	1052	366	470	CL/LD1/LD2
19 /plane 1	925	312	400	DES/DCL/LC2
\plane 2	1000	244	519	CL/DDES/LD2
19 /plane 1	975	394	419	DES/DCL/LC2
\plane 2	984	250	334	CL/LD2
		Encounter 21		
Expected /plane 1	ignores advisories			
\plane 2	756	530	man 531	DES/DCL
21 plane 2	525	362	man 650	DES/DCL/LC2
21 plane 2	672	598	man *	DES
21 plane 2	449	360	man 548	DCL/DES

Note: The initial DCL advisory was ignored.

TABLE D-5. EXPECTED AND ACTUAL ALTITUDE SEPARATIONS AND DEVIATIONS BY ENCOUNTER (IN FEET) (CON'T)

Run Number	Altitude Separation at CPA	Altitude Deviation at CPA	Maximum Altitude Deviation	RA List
		Encounter 22		
Expected /plane 1	448	942	1396	CL/ICL/CL
\plane 2	ignores advisories			
22 plane 1	572	1037	1391	CL/ICL/CL
22 plane 1	406	562	656	DDES/CL
22 plane 1	844	1119	1213	CL/ICL/DDES/CL
		Encounter 23		
Expected /plane 1	1100	768	856	CL/ICL/CL/LD2
\plane 2	1100	95	man 280	DES/LC2
23 plane 1	1069	258	391	CL/DDES/LD2
23A plane 1	1188	317	472	CL/LD5/LD2
23 plane 2	1050	225	man 544	DES/LC2/LC1/DES
23 /plane 1	750	138	389	DDES/CL/LD2
\plane 2	997	349	man 529	DES/LC2
23 plane 1	275	650	1037	DDES/CL/ICL
23B/plane 1	475	357	507	CL/DDES/LD5/CL
\plane 2	659	41	man 124	DES/LC2/LC1
		Encounter 24		
Expected /plane 1	1126	245	255	DES/LC1/LC2
\plane 2	1126	350	man 360	CL/LD2
24 plane 1	1306	331	339	DES/LC5/LC2
24 plane 2	1431	569	man 738	CL/LD1/LD2
24 /plane 1	906	507	607	DES/LC2
\plane 2	806	965	man 1068	CL/ICL/LD5
24 plane 1	1587	543	618	DES/IDES/DES/LC2

TABLE D-6. PILOTS AND PERFORMED ENCOUNTERS

Pilot -affiliation	Runs Flown															Total Flown
Wally Gillman -American	2	2A	**4**					**6B**		**7** (6A)		**8** (6)		12		7
Bill Stanford -USAF	2		**4**													2
Ross Beins -United	2	2A	4	4A	**4B**	**4C**	6	6A	6B	**6C**	**7**		**8**		12	13
Al Mattox -American	2	2A	**4**					**6B**		7		**8** (6	**8A** 6A)		12	8
Ed Briggs -Delta	2	2A	**4**				**6**				**7**		**8**		12	7
Arnie Reiner -Pan American	2	2A	4		4B	**4C**	**6**				**7**		**8** (4A)		**12**	9
Bill Stine -NBAA	2															1
Sam Schirk -Continental	2	2A	4	**4A**			6	**6A**			7	7A	**7B**	**8**	12	11
Bill Herndon -Pan American	2	2A	**4**				**6**				**7**			8	12	7
Steve Bazer -Delta	2	2A	4	**4A**			6	6A			**7**			**8**	12	9
Tom McBroom -American	2	2A	**4**				**6**				**7**			**8**	12	7
Bob Buley -Northwest	2		4	4A	**4B**		**6**				**7**			8	**8A** 12	9
Duane Adelman -Northwest	2	2A	**4**					6A	6B	**6C**	**7** (6)			**8**	12	9
TOTALS	23		21				18				13			13	11	99

NOTE: Runs with a letter after the number (i.e., 2A) indicate that the encounter was repeated. Runs with numbers in parenthesis below them indicate that the encounter in parenthesis was attempted, but the actual flight geometry resulted in the issuance of advisories commensurate with the credited encounter. (i.e., Encounter 6 was attempted, but the resulting advisories were those desired for Encounter 7.) Runs in bold type resulted in an invalid advisory alternative RA (IAARA).

TABLE D-7. TABULAR LISTING: AURAL ADVISORIES GENERATED BY TCAS

Note: The aural advisories were recorded in the cockpit with a cassette tape recorder. These aural advisories are arranged in the order of occurrence. The date of the flight and the TCAS system installed for each set of encounters is included. Question marks appear when data was missing from the cassette tape.

Runs which generated questions and criticism from pilots are denoted by underlining the run number. Analysis of these runs is included in Appendix C, Runs of Interest.

The run numbers indicate the pilot and encounter number, and repetition of each run.

Bendix TCAS-II

6/6/89 Aural Advisories

Run 1-2 traffic traffic / traffic / descend descend / vertical speed restricted / traffic traffic

Run 1-2A traffic traffic / descend descend descend / maintain vertical speed / vertical speed restricted / vertical speed restricted / clear of conflict

Run 1-4 traffic traffic / climb crossing climb climb crossing climb / descend descend now descend descend now / maintain vertical speed

Run 1-8 (6) traffic traffic / descend crossing descend descend crossing descend / maintain vertical speed / increase descend increase descend

Run 1-7 (6A) traffic traffic / climb climb climb / increase climb increase climb / increase climb increase climb / climb

Run 1-6B traffic traffic / vertical speed restricted vertical speed restricted / descend crossing descend descend crossing descend / climb climb now climb climb now / maintain vertical speed / climb climb climb

Run 1-12 ? / descend descend descend / maintain vertical speed

Run 2-2 traffic traffic / descend descend descend / maintain vertical speed / vertical speed restricted / vertical speed restricted / clear of conflict / traffic

Run 2-4 traffic traffic / vertical speed restricted vertical speed restricted / climb crossing climb climb crossing climb / descend descend descend / vertical speed restricted

TABLE D-7. TABULAR LISTING: AURAL ADVISORIES GENERATED BY TCAS (CON'T)

Run 3-2 ? / descend descend descend / vertical speed restricted / vertical speed restricted / clear of conflict

Run 3-2A traffic traffic / descend descend descend / maintain vertical speed / vertical speed restricted

Run 3-4 traffic traffic /descend descend descend / vertical speed restricted

Run 3-4A traffic traffic / descend descend descend / vertical speed restricted

Run 3-4B traffic traffic / vertical speed restricted vertical speed restricted / descend descend now descend descend now / vertical speed restricted / reduce vertical speed reduce vertical speed

Run 3-4C traffic traffic / climb crossing climb climb crossing climb / descend descend now descend descend now / maintain vertical speed / vertical; speed restricted / clear of conflict

Run 3-6 traffic traffic / traffic / traffic / climb climb climb / traffic

Note: Some of these TAs may be from targets of opportunity.

Run 3-6A traffic traffic / descend crossing descend descend crossing descend / maintain vertical speed / descend descend descend / maintain vertical speed

6/8/89 Aural Advisories

Run 4-2 traffic traffic / descend descend descend / maintain vertical speed / vertical speed restricted / vertical speed restricted / clear of conflict

Run 4-2A traffic traffic / descend descend descend / maintain vertical speed / vertical speed restricted / vertical speed restricted / clear of conflict

Run 4-4 traffic traffic / traffic / climb crossing climb climb crossing climb / descend descend descend / vertical speed restricted / clear of conflict

TABLE D-7. TABULAR LISTING: AURAL ADVISORIES GENERATED BY TCAS (CON'T)

Run 4-8 (6) traffic traffic / descend crossing descend descend crossing descend / maintain vertical speed / increase descend increase descend / increase descend increase descend / traffic

Run 4-8A (6A) traffic traffic / descend descend descend / increase descend increase descend / increase descend increase descend

Run 4-6B traffic traffic / descend crossing descend descend crossing descend / climb climb now climb climb now / maintain vertical speed / vertical speed restricted / traffic

Run 4-7 ?

Run 4-12 traffic traffic / descend descend descend / maintain vertical speed / descend descend descend / maintain vertical speed

Run 5-2 traffic traffic / descend descend descend / maintain vertical speed / descend descend descend / vertical speed restricted / clear of conflict

Run 5-2A traffic traffic / descend descend descend / maintain vertical speed / traffic / traffic

Run 5-4 traffic traffic / climb crossing climb climb crossing climb / descend descend now descend descend now / vertical speed restricted / traffic traffic

Run 5-6 traffic traffic / descend crossing descend descend crossing descend / climb climb now climb climb now / maintain vertical speed / vertical speed restricted / reduce vertical speed reduce vertical speed

Run 5-7 traffic traffic / climb climb climb / maintain vertical speed / increase climb increase climb / increase climb increase climb / clear of conflict

Run 5-8 traffic traffic / descend descend descend / maintain vertical speed / descend descend / increase descend increase descend / increase descend increase descend / clear of conflict

Run 5-12 traffic traffic / descend descend descend / maintain vertical speed

TABLE D-7. TABULAR LISTING: AURAL ADVISORIES GENERATED BY TCAS (CON'T)

Honeywell TCAS-II

6/19/89 Aural Advisories

Run 6-2 traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / traffic traffic

Run 6-2A traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / clear of conflict / traffic traffic

Run 6-4 traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / traffic traffic

Run 6-8 (4A) traffic traffic / descend descend descend / increase descend increase descend / maintain vertical speed maintain vertical speed / vertical speed restricted vertical speed restricted

Run 6-4B traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / traffic traffic

Run 6-4C traffic traffic / climb crossing climb climb crossing climb / descend descend now descend descend now / maintain vertical speed maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

Run 6-6 traffic traffic / vertical speed restricted vertical speed restricted / climb climb now climb climb now / maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

Run 6-7 traffic traffic / climb climb climb / maintain vertical speed / increase climb increase climb / maintain vertical speed maintain vertical speed / climb climb climb / traffic traffic

Run 6-12 traffic traffic / climb crossing climb climb crossing climb / descend descend now descend descend now / maintain vertical speed maintain vertical speed / vertical speed restricted vertical speed restricted / descend descend descend / maintain vertical speed maintain vertical speed / descend descend descend / maintain vertical speed maintain vertical speed / clear of conflict

Run 7-2 traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / clear of conflict

Run 8-2 traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / clear of conflict

TABLE D-7. TABULAR LISTING: AURAL ADVISORIES GENERATED BY TCAS (CON'T)

Run 8-2A traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / clear of conflict / traffic traffic

Run 8-4 traffic traffic

Run 8-4A traffic traffic / climb crossing climb climb crossing climb / descend descend now descend descend now / increase descend increase descend / maintain vertical speed maintain vertical speed / traffic traffic

Run 8-6 traffic traffic / climb climb climb / maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

Run 8-6A traffic traffic / vertical speed restricted vertical speed restricted / descend crossing descend / climb climb now climb climb now / maintain vertical speed maintain vertical speed / vertical speed restricted / reduce vertical speed reduce vertical speed / traffic traffic

Run 8-7 traffic traffic / climb climb climb / maintain vertical speed maintain vertical speed / clear of conflict / traffic traffic

Run 8-7A traffic traffic / climb climb climb / maintain vertical speed maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

Run 8-7B traffic traffic / climb climb climb / increase climb increase climb / maintain vertical speed maintain vertical speed / vertical speed restricted vertical speed restricted / reduce vertical speed reduce vertical speed / traffic traffic

Run 8-8 traffic traffic / descend descend descend / increase descend increase descend / maintain vertical speed maintain vertical speed / descend descend descend / traffic traffic

Run 8-12 traffic traffic / descend descend descend / maintain vertical speed maintain vertical speed / descend descend descend / maintain vertical speed maintain vertical speed / clear of conflict

6/20/89 Aural Advisories

Run 9-2 traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / traffic traffic

TABLE D-7. TABULAR LISTING: AURAL ADVISORIES GENERATED BY TCAS (CON'T)

Run 9-2A traffic traffic / descend descend descend / maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

Run 9-4 traffic traffic / climb crossing climb climb crossing climb / descend descend now descend descend now / maintain vertical speed / vertical speed restricted vertical speed restricted / reduce vertical speed reduce vertical speed / traffic traffic

Run 9-6 traffic traffic / vertical speed restricted vertical speed restricted / climb climb now climb climb now / maintain vertical speed / vertical speed restricted vertical speed restricted / reduce vertical speed reduce vertical speed / traffic traffic

Run 9-7 traffic traffic / climb climb climb / maintain vertical speed maintain vertical speed / increase climb increase climb / maintain vertical speed maintain vertical speed / traffic traffic

Run 9-8 traffic traffic / descend descend descend / maintain vertical speed maintain vertical speed / traffic traffic

Run 9-12 traffic traffic / descend descend descend / maintain vertical speed / vertical speed restricted / maintain vertical speed / descend descend descend / clear of conflict

Run 10-2 traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / traffic traffic

Run 10-2A traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / traffic traffic

Run 10-4 traffic traffic / descend descend descend / maintain vertical speed maintain vertical speed / vertical speed restricted vertical speed restricted / reduce vertical speed reduce vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

Run 10-4A traffic traffic / climb crossing climb climb crossing climb / descend descend now descend descend now / maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

Run 10-6 traffic traffic / climb climb climb / maintain vertical speed maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

TABLE D-7. TABULAR LISTING: AURAL ADVISORIES GENERATED BY TCAS (CON'T)

Run 10-6A traffic traffic / climb climb climb / maintain vertical speed maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

Run 10-7 traffic traffic / climb climb climb / maintain vertical speed maintain vertical speed / increase climb increase climb / maintain vertical speed maintain vertical speed / traffic traffic

Run 10-8 traffic traffic / descend descend descend / maintain vertical speed maintain vertical speed / increase descend increase descend / maintain vertical speed maintain vertical speed / traffic traffic

Run 10-12 traffic traffic / vertical speed restricted vertical speed restricted / descend descend descend / maintain vertical speed / vertical speed restricted vertical speed restricted / descend descend descend / maintain vertical speed / vertical speed restricted / maintain vertical speed maintain vertical speed / descend descend descend / maintain vertical speed / descend descend descend / maintain vertical speed maintain vertical speed / descend descend descend / clear of conflict

6/22/89 Aural Advisories

Run 11-2 traffic traffic / descend descend descend / maintain vertical speed / vertical speed restricted vertical speed restricted / clear of conflict / traffic traffic

Run 11-2A traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / clear of conflict / traffic traffic

Run 11-4 traffic traffic / climb crossing climb climb crossing climb / descend descend now descend descend now / vertical speed restricted vertical speed restricted / traffic traffic

Run 11-6 traffic traffic / descend crossing descend descend crossing descend / climb climb now climb climb now / maintain vertical speed maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

TABLE D-7. TABULAR LISTING: AURAL ADVISORIES GENERATED BY TCAS (CON'T)

Run 11-7 traffic traffic / climb climb climb / increase climb increase climb / maintain vertical speed maintain vertical speed / climb climb climb / traffic traffic / maintain vertical speed / climb crossing climb climb crossing climb / descend descend now descend descend now / maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

Note: This run included an RA sequence on a target of opportunity.

Run 11-8 traffic traffic / descend descend descend / increase descend increase descend / maintain vertical speed maintain vertical speed / traffic traffic

Run 11-12 traffic traffic / descend descend descend / maintain vertical speed / descend descend descend / maintain vertical speed maintain vertical speed / vertical speed restricted / maintain vertical speed / descend descend descend / vertical speed restricted vertical speed restricted / maintain vertical speed maintain vertical speed / descend descend descend / clear of conflict

Run 12-2 traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / clear of conflict / traffic traffic

Run 12-4 traffic traffic / traffic traffic

Run 12-4A traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / traffic traffic

Run 12-4B traffic traffic / climb crossing climb climb crossing climb / descend descend now descend descend now / maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

Run 12-6 traffic traffic / descend crossing descend descend crossing descend / climb climb now climb climb now / maintain vertical speed maintain vertical speed / climb climb climb / traffic traffic

Run 12-7 traffic traffic / climb climb climb / maintain vertical speed / increase climb increase climb / maintain vertical speed maintain vertical speed / climb climb climb

Run 12-8 traffic traffic / descend descend descend / maintain vertical speed maintain vertical speed / clear of conflict / traffic traffic

TABLE D-7. TABULAR LISTING: AURAL ADVISORIES GENERATED BY TCAS (CON'T)

Run 12-8A traffic traffic / descend descend descend / increase descend increase descend / maintain vertical speed maintain vertical speed

Run 12-12 traffic traffic / descend descend descend / maintain vertical speed maintain vertical speed / clear of conflict

6/23/89 Aural Advisories

Run 13-2 (pop up) traffic traffic / descend descend descend / maintain vertical speed / traffic traffic

Run 13-2A traffic traffic / descend descend descend / vertical speed restricted vertical speed restricted / traffic traffic

Run 13-4 traffic traffic / climb crossing climb climb crossing climb / descend descend now descend descend now / descend descend descend / vertical speed restricted vertical speed restricted / traffic traffic / traffic traffic

Run 13-6 (7) traffic traffic / climb climb climb / increase climb increase climb / maintain vertical speed maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic /

Run 13-6A traffic traffic / climb climb climb / maintain vertical speed / vertical speed restricted vertical speed restricted / traffic traffic

Run 13-6B traffic traffic / vertical speed restricted vertical speed restricted / traffic traffic

Run 13-6C traffic traffic / descend crossing descend / climb climb now climb climb now / maintain vertical speed maintain vertical speed / vertical speed restricted vertical speed restricted / clear of conflict / traffic traffic

Run 13-8 traffic traffic / descend descend descend / maintain vertical speed maintain vertical speed / increase descend increase descend / maintain vertical speed maintain vertical speed / traffic traffic

Run 13-12 traffic traffic / descend descend descend / maintain vertical speed maintain vertical speed / descend descend descend / maintain vertical speed maintain vertical speed / descend descend descend / maintain vertical speed maintain vertical speed / vertical speed restricted / maintain vertical speed / descend descend descend / maintain vertical speed maintain vertical speed / descend descend descend

TABLE D-8. TABULAR LISTING: RESPONSES TO POST-ENCOUNTER QUESTIONS

Note: The pilot responses to the questions varied considerably, but most responses were favorable towards TCAS performance and interfaces. Those responses which were unfavorable towards TCAS, or different from the majority of the responses, are identified by the run number. Those runs included in Appendix C, Runs of Interest, are underlined.

Some of the responses have been paraphrased for clarity. Repeated responses are listed only once.

How was your workload affected?

small increase / minimum / moderate increase / minimal increase / moderate increase / slight increase / slightly / not appreciably / not / not at all / wasn't / normal / very little / increased, but not a problem / increased, but manageable / no problem with workload / I was distracted looking between looking for the target and looking at the TCAS display...finally gave up looking for the target and followed TCAS / It didn't increase it one bit / no effect / not appreciably / I was pretty busy (run 9-2) / Not bad for an encounter with another airplane / Badly, I didn't like that at all. I didn't get the target (visually) very soon, and when I got it, I disagreed with the command. It (climbing) looked like a bad idea to me. I thought I should have descended right then, but I didn't know for sure. You never know for sure that you're seeing what's on here, so you gotta follow the commands. He looked like he was above me and I should go down. (run 9-4) / It was appropriate... a reasonable workload for this situation / Pretty adversely. I kept trying to look at him, but I would have called ATC (air traffic control) and asked for an avoidance vector (run 9-12) / No increase. I think my workload would have been reduced over a typical ATC call. / no effect / basically the same / decreased, no increase / I was tied up with the initial traffic and advisory, but it was not overwhelming. You are pretty busy in the TCAS maneuver. / No problem. None whatsoever / Slightly increased, only because of the awareness of the traffic around. But on the other hand, with the conflict it was reduced. In other words, if I'd seen the other traffic, I'd have had to make a decision as to what to do. The system helped me make that decision. / Increased while deciding what to do (because of the reversal). Decreased after that. (run 13-6) / Decreased

Were the alarms issued in a timely manner?

yes / yes, except for the reversal, which was too late towards the end (run 2-4) / No. If it wanted me to climb, it should have started the climb way sooner (run 9-4) / Not really because he was there forever and I felt like it should have done something. I know it can't tell me to turn, but that's what I wanted to

TABLE D-8. TABULAR LISTING: RESPONSES TO POST-ENCOUNTER QUESTIONS (CON'T)

know... which way to turn. (run 9-12) / yes, except for the ambiguous commands. (Run 10-12)

Were the alarms clear and unambiguous?

yes, except for one case when an aural alarm was issued, and there was no indication on the IVSI when I looked. This was a little bit confusing. / yes / yes, except for the times when the aural alarm was still finishing a phrase while the IVSI was displaying a different command (most troublesome on the reversal) / yes, except for the "vertical speed restricted" enunciation, which had not been explained to me prior to the flight. What went through my mind was, am I doing the right vertical speed? Upon hearing the explanation of the enunciation meaning, I had no further difficulties. / No. Quick changes on the IVSI are confusing (Run 9-12) / yes, except in Run 10-12 / yes, except the maintain immediately after the increase descend command (run 13-4), and the voice commands during the reversal (needed to look at the IVSI) (run 13-6).

Were the commands useful on avoiding situations that were dangerous, or had the potential to become dangerous?

yes / most definitely, yes / sure, yes

note: This question was deleted from the question list after the first pilot evaluation flight since all the runs were or had the potential to become dangerous.

Did following any of the commands seem to make the situation more dangerous?

no / (One pilot commented that on several runs he followed the advisories because he could not discern the movement in the other aircraft visually.) / Yes. I would have continued the descent. I'd let him go by before I stopped descending. (run 9-2) / Yes. The first one. (the climb advisory) (run 9-4) / less dangerous

Were there situations when another advisory would have been preferred, or an advisory was inappropriate?

no, except the aural commands (vertical speed restricted) are not clear, the missing (clear of conflict) is confusing (because of the track drops), the soften command after an increase could have been issued earlier (run 1-7), the last climb was inappropriate (after a maintain vertical speed advisory) (run 1-6) / no, except the aural for the reversal should have been "descend now" instead

TABLE D-8. TABULAR LISTING: RESPONSES TO POST-ENCOUNTER QUESTIONS (CON'T)

of just "descend" (run 2-4) / no, except it is inappropriate to drop track and therefore not issue a "clear of conflict", and there was an extraneous "vertical speed restricted" with no indication on the IVSI (run 3-4B).

Note: This question was split into the two following questions following the first pilot evaluation flight.

Were any advisories inappropriate?

no / I couldn't tell. There were several advisories going on. I don't know. We passed them. I guess it was appropriate. / no, except Run 6-7 when a climb was issued after passing the target / no, except for an advisory after we'd passed. Very disconcerting (run 8-2A) / yes, the "vertical speed restricted" (run 9-2) / no, except the traffic alerts after the encounter is over, and the usage of maintain vertical speed when the proper vertical speed is reached.

Would you have preferred any different advisories?

no / no, except I was surprised it took us in the direction it did. It looked like if we'd continued in a descend we'd have been better off. That was my visual perception. (run 8-4A) / We should have got an "increase". It (the advisory) didn't help as much as it should have. The lack of the "increase" was inappropriate. (run 8-7)

Note: When the pilot was asked if he hadn't been expecting an "increase" during this encounter, would he still have a problem with the TCAS performance, he responded: "Yes. I think the separation was a little bit tight."

/ Yes. Let him go by before they said maintain altitude - don't climb (run 9-2) / If I ever sort it out I would probably say it should have given me a "climb", but from what I can see it looked okay. It was appropriate. (run 9-8) / The shifting back and forth is confusing. I would have preferred a solid advisory until the conflict had ended (run 10-12) / no, except the "clear of conflict" enunciation should be present, and the "climb" enunciation is confusing when softening from an Increase Climb to a standard Climb.

TABLE D-8. TABULAR LISTING: RESPONSES TO POST-ENCOUNTER QUESTIONS (CON'T)

Was the displacement from the normal flight path of concern?

significant, but not of concern (over 300 ft) (run 1-2) / no / yes (runs 1-7 and 1-12) / yes, moderate concern (run 1-6) / slightly (run 2-2)

note: This question was reworded for clarity after the first flight to the following.

Were you concerned with the course (altitude) deviation?

Note: Remarks in parentheses were made to pilots to get additional information about their previous responses.

no / Yes, I don't like going out in no mans land. I know I'm on the road. What do I want to go down for? (run 5-2) / Yes, I was concerned. I don't like to deviate. (run 5-2A) / Yes, I don't like flying all over the sky. (What would you prefer to do instead of following the the TCAS advisory?) Remain at my clearance, at my flight level. (It sounds like you don't want a TCAS.) No, but I am concerned. God, how can I not be concerned after that, I mean, I wouldn't fly the next leg of the trip. I'd probably call the chief pilot and tell him I was off, we were done. (run 5-4) / In another environment, yes. Here, no. / Here, no. Not at this altitude. / yes / Yes I was. In an IFR (instrument flight rule environment), I would have talked to the center to tell him I'm out of 12300' (run 9-2) / Yes, but not like the time before. (run 9-2A) / Yes, very much so (run 9-8) / I was concerned that it was taking so long to resolve the conflict. (run 10-12) / no, since we were flying VFR / no, except in runs 13-6, 13-7, and 13-8 I was concerned about crossing other flight levels.

How easily was visual contact of the target aircraft achieved using the position data presented on the TCAS display?

slightly easier / easily / relatively easy / moderately easy / quite easy / easy / very easy / easier / difficult because two planes were sighted, but only one was displayed, and I didn't know which of the two was on the TCAS display. (*note: The second plane was a military aircraft.)*

Note: This question was rephrased for clarity after the first flight to the following.

TABLE D-8. TABULAR LISTING: RESPONSES TO POST-ENCOUNTER QUESTIONS (CON'T)

Did the TCAS display data help you sight the target?

yes / I didn't see him. I was too busy trying to fly the RAs. I picked him up at the last minute. (Run 5-4) / No, never saw it. (Run 5-8) / yes, except in run 6-8. I knew where to look, but I couldn't see it. / In run 6-7, I knew where to look. I had trouble acquiring him. I think this was partially due to being unfamiliar with the range presentation on the display. / yes, definitely / I sighted the wrong target (run 10-6) / Not that time (run 11-2)

Was visual acquisition of the target made before the advisory?

no (run 1-2) / yes / at the same time (run 3-4)

Note: This question was rephrased for clarity after the first flight to the following.

Did you see the target plane before the RA?

yes / no (runs 5-2, 5-2A, 5-4, 5-7, 5-8) / just about at the same time (6-2A) / no (run 6-8) / no (run 10-6) / no, I was concentrating on another plane (run 13-2) / no (runs 13-4 and 13-8)

Was visual contact maintained on the target throughout the maneuvers?

no, until starting the maneuver (run 1-2) / yes / yes, except when looking in the cockpit / no, acquired during the maneuvers (run 5-2) / no (runs 5-4, 5-7, 5-8) / no (run 6-4C) / in run 6-7 the aircraft nose blocked my view / no, lost sight of it when the nose was pulled up (runs 9-6 and 9-7) / no, didn't pick him up (run 10-6) / no, lost sight of him under the airplane (run 10-6A)

Overall, what was your opinion of the TCAS performance?

It was good, okay, / performance was good, but I was uneasy about the separation at CPA (run 1-4) / TCAS did good, it was good / terrible because of the target drop, but good until the target drop (run 1-12) / good / very good, nice, very nice / excellent / it works great / it was good / it worked well / I thought it worked well / I thought it worked as advertised / I thought it worked satisfactorily / It's better than not having it, that's for darn sure / great / excellent / a little shaky (Run 8-7) / It worked as it's supposed to / It did well / It screwed up (run 9-4) / Good. It was appropriate / Quite good / It was good / Fair

TABLE D-8. TABULAR LISTING: RESPONSES TO POST-ENCOUNTER QUESTIONS (CON'T)

(run 9-12) / excellent / Only fair on this run. (run 10-12) / It worked adequately / excellent / seemed to be working good / worked well

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